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Elongation in 2", % (min)	18	17	16
Reduction of Area, % (min)	55*	50	45

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900	44.0	59.5	44.0
1,000	10.5	23.0	13.8
1,100	2.3	10.0	5.8

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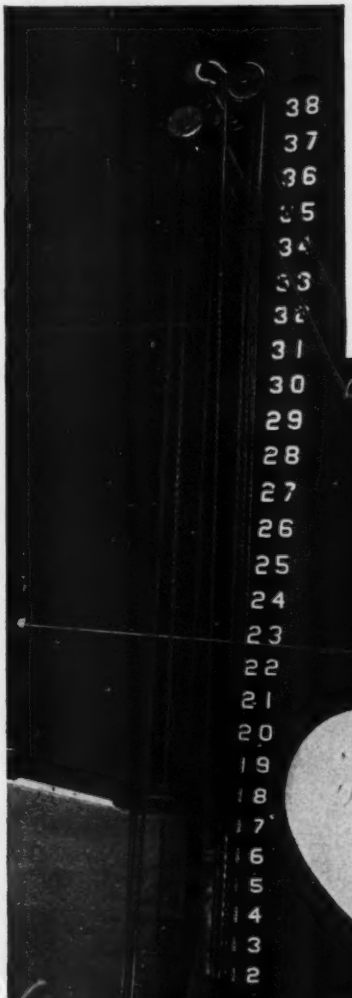

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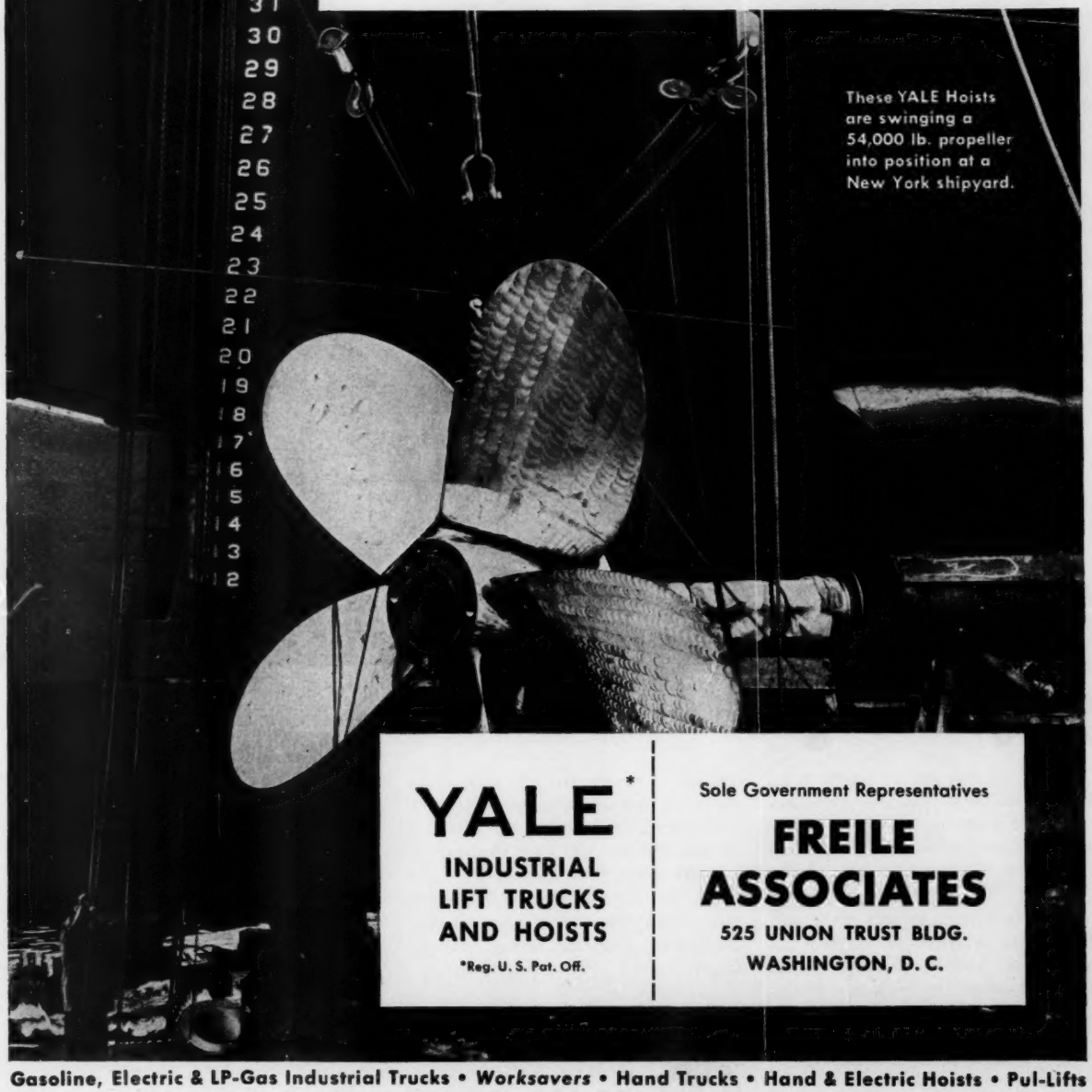

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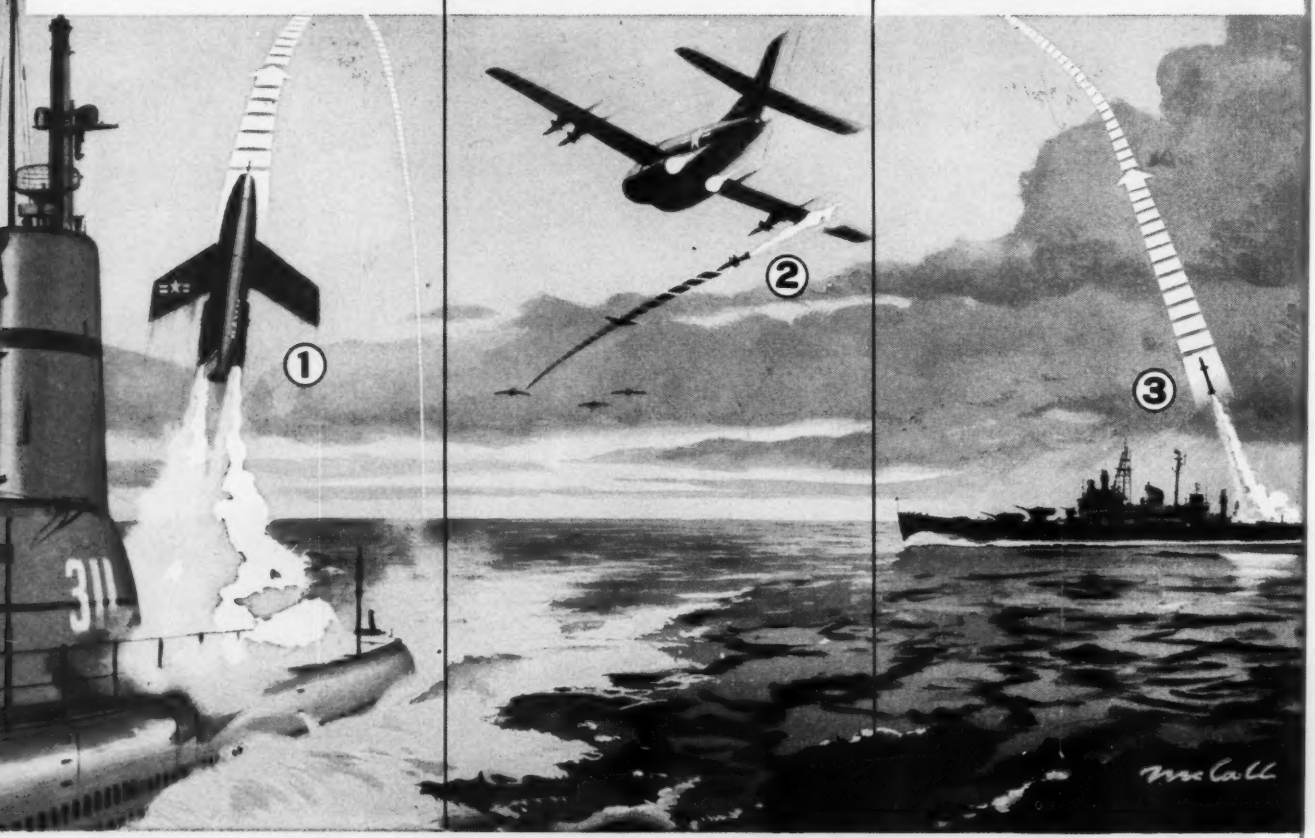
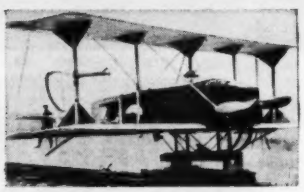


NEW NAVY MIGHT EMPLOYS MISSILES OF ALL TYPES

The U. S. Navy has come a long way from the world's first missile, shown at right, to the missiles employed in the fleet today. Our modern Navy, with its modern weapons, has new tactical power to strengthen our nation's defenses. Sperry, too, has come a long way since its pioneering work in gyroscopics and missiles. Today Sperry is putting its many capabilities to work in seven major missile systems—of all types—ranging from complete systems' cognizance to major sub-system responsibility.



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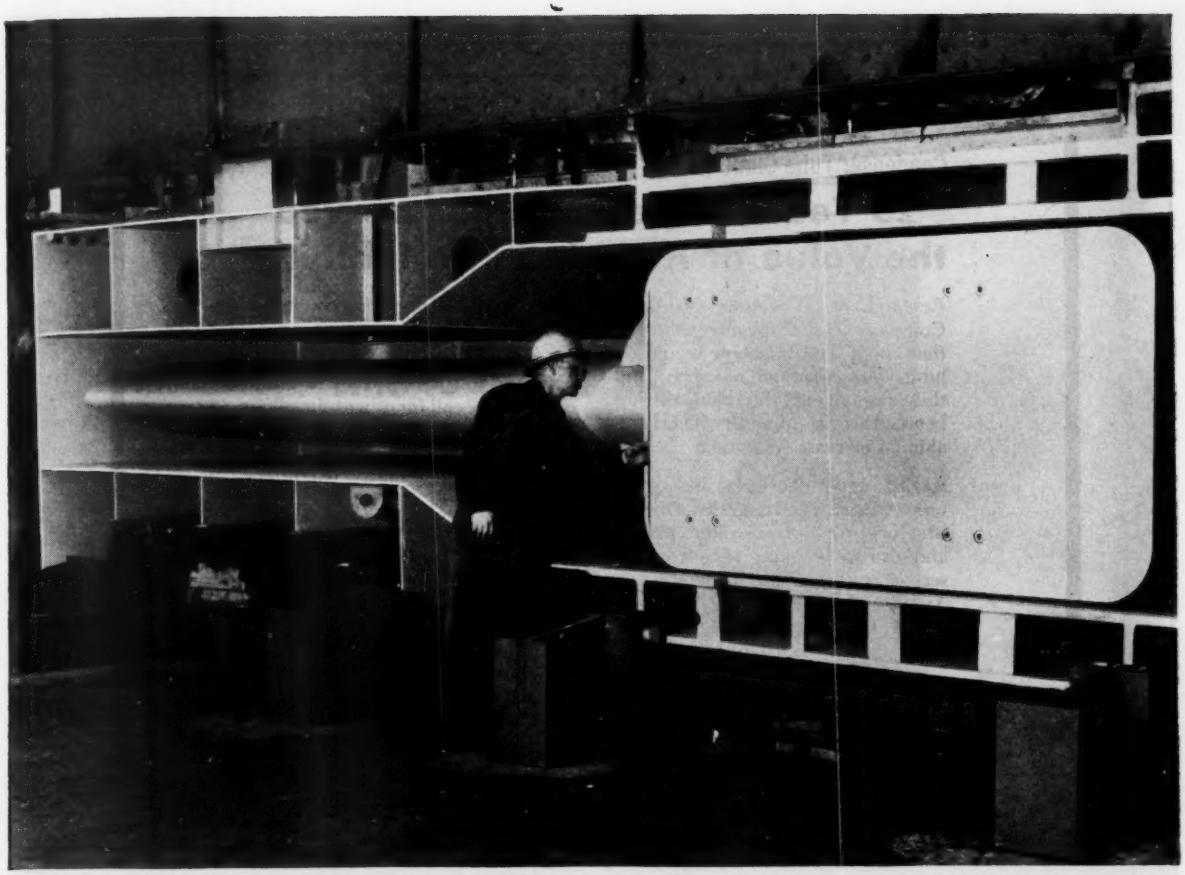

Fin, Fin Box and Machinery Unit, produced by Newport News for the "Gyrofin" ship stabilizer developed by Sperry Gyroscope Company, occupies but little space . . . a recess of 8 feet in the hull. This unit is part of two sets built by Newport News for installation on the Matson Lines' *Mariposa* and *Monterey*. Newport News recently completed a similar set for the U. S. Navy.

Newport News puts "know-how" into fins designed to cut ship's roll as much as 90%

The "fin" shown here is less than 15 feet long. Yet—two of them can stop the roll of a 20-thousand-ton ship!

They're part of the amazing new Sperry Gyrofin* Ship Stabilizer. Together, these "fins" deliver up to 6000 foot-tons of "lift" or anti-rolling movement. They keep a 20-thousand-ton ship smooth, steady and on its course. Result: new high levels of sustained speeds . . . increased propulsion efficiency and freedom from boarding seas in rough weather.

In announcing their Gyrofin to the maritime industry, Sperry Gyroscope Company significantly declared they had ". . . *engaged the hydro-dynamic experience and shipbuilding facilities of the Newport News Shipbuilding and Dry Dock Company.*"

Newport News tested hydro-dynamic scale models to determine Gyrofin system design characteristics. And to detect possible stress concentration points in the fin itself, with typical thoroughness Newport News made stress analyses of individual components in the plant's Hydraulic Laboratory.

Comprehensive Newport News "know-how". . . including decades of metal working experience . . . goes into actual building of the stabilizers. Into castings, weldments, steel fabrication and extensive machine shop work.

Send for the recently published, easy-to-read, illustrated booklet, "Facilities and Products." It describes how Newport News "know-how" might serve you.

*T.M.

Engineers. . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

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Shipbuilding and Dry Dock Company
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25 Years' Experience has proved the Value of Arsenic as an Inhibitor

Research at The American Brass Company nearly 25 years ago showed that about 0.04% arsenic would inhibit dezincification of brass, and this amount of the element has been added to Admiralty metal and aluminum brass since then.

MARINE USERS generally find ANACONDA Arsenical Admiralty-439 satisfactory for inland-water vessels and also for seagoing vessels where service conditions are moderate; but ANACONDA Ambraloy-927 is preferred for most seagoing vessels. Both alloys are resistant to dezincification under all corrosive conditions found in these services.

YOUR OWN NEEDS may call for these corrosion-resistant Anaconda alloys or they may call for other tube alloys we make. Our Technical Department will be glad to help you select the one best alloy for the conditions you face.

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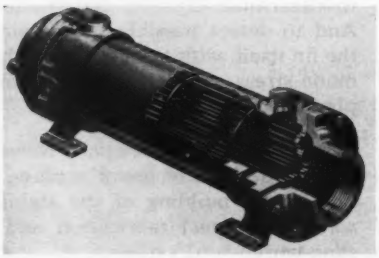

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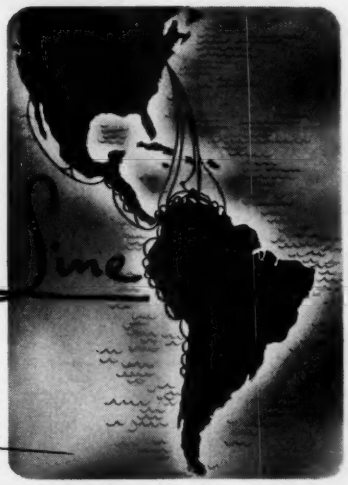

It is a direct and very important link with this country and Latin America. More than just a pleasure route on which the Grace Line "Santas" ply their ways, it is a line that joins two continents together in understanding and good will.

For more than a century, Grace Line ships have traveled these routes carrying passengers and cargo to and from North America's best friends. It is an "ambassadorial mission" of long and good standing.

This will continue. In a program that will eventually result in the replacement of the entire Grace Line fleet, the Newport News Shipbuilding and Drydock Company was awarded contracts for the construction of the first two vessels. To replace the present Santa Rosa and Santa Paula, the new ships will be of the express liner type of approximately 20,000 tons displacement each.

Steam power for each ship will be furnished by three 2-drum type B&W Marine Boilers. The latest advance in marine steam engineering, the B&W 2-drum type boiler incorporates outstanding installation, operating and maintenance features that, under all conditions, result in complete safety and efficiency.

B&W and Marine Boilers are a combination with more than 80 years' experience. It is the kind of experience that has powerfully proved itself in almost every type of ship you can think of — both naval and merchant. The Babcock & Wilcox Company, Boiler Division, 161 East 42nd Street, New York 17, N. Y.

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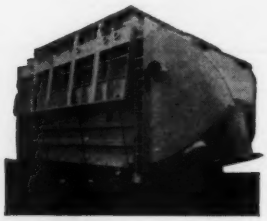
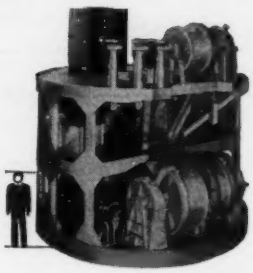
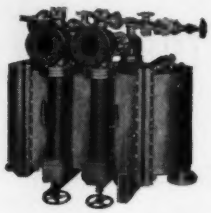


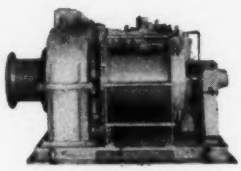
Dual Bank Steam Condenser



Boat and Airplane Crane

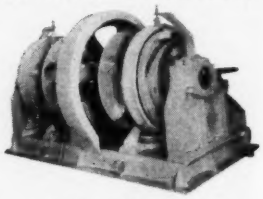


Tubejet Steam Jet Air Ejector



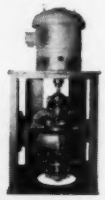
Cargo Winch

Automatic Tensioning Hoist — Airplane Crane

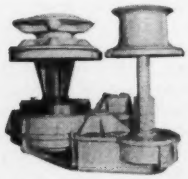


Anchor Windlass

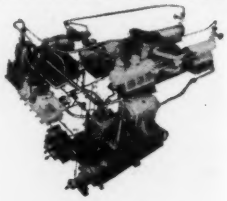
Electric Warping Capstan



Marine Type Fire Pump Arranged in Vertical Position



Electric Hydraulic Windlass



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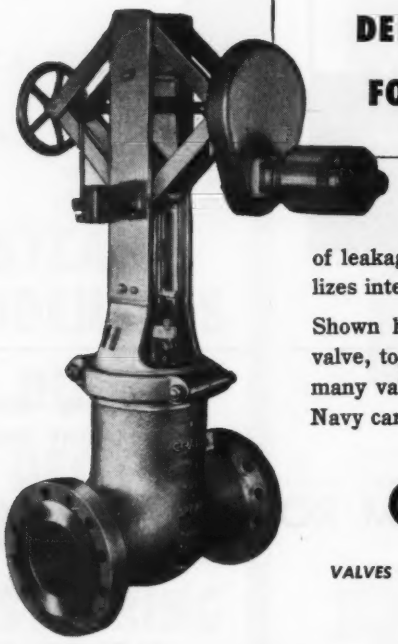

DEPENDABLE STEAM CONTROL FOR NAVY'S NEW CATAPULTS

This Crane valve design for high-pressure/high-temperature steam service eliminates problems of leakage and maintenance at the bonnet joint. It utilizes internal line pressure to keep the bonnet joint tight.

Shown here is a Crane 600-pound Pressure-Seal gate valve, toggle-operated with air motor. It's typical of the many valves Crane is supplying for catapult service on Navy carriers both new and conversions.

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SUPERSTRUCTURE OF KAISER ALUMINUM

on the world's largest icebreaker

Admiral Byrd, on his recent expedition "Operation Deep Freeze" to the South Pole, was aboard the U.S.S. Glacier—the first icebreaker of its class—built for the U.S. Navy by Ingalls Shipbuilding Corporation, Pascagoula, Miss.

Some of the superstructure aboard this ultramodern ship was made of lightweight, rustproof Kaiser Aluminum . . . another example of the growing use of Kaiser Aluminum in the marine industry.

Aluminum superstructures mean less topside weight, a lower center of gravity, greater stability. Less weight also makes possible greater fuel capacity, hence longer range or higher speeds without increasing power.

And Kaiser Aluminum alloys for marine use are highly corrosion resistant, thus greatly reducing costs of painting, maintaining and refitting.

Our marine engineers will be happy to work with you to help solve problems of alloy selection, fabrication and design. They will make available to you Kaiser Aluminum's extensive research facilities and engineering experience.

For immediate attention, contact your local Kaiser Aluminum sales office. *General Sales Office*, Palmolive Bldg., Chicago 11, Illinois; *Executive Office*, Kaiser Bldg., Oakland 12, California.

Kaiser Aluminum

See "THE KAISER ALUMINUM HOUR." Alternate Tuesdays, NBC Network. Consult your local TV listing.

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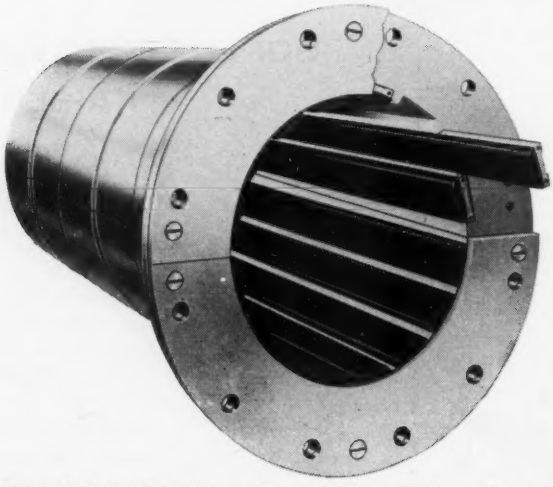

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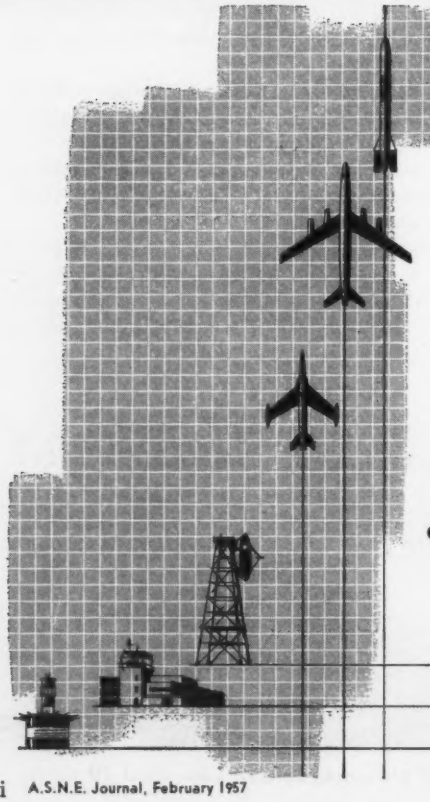

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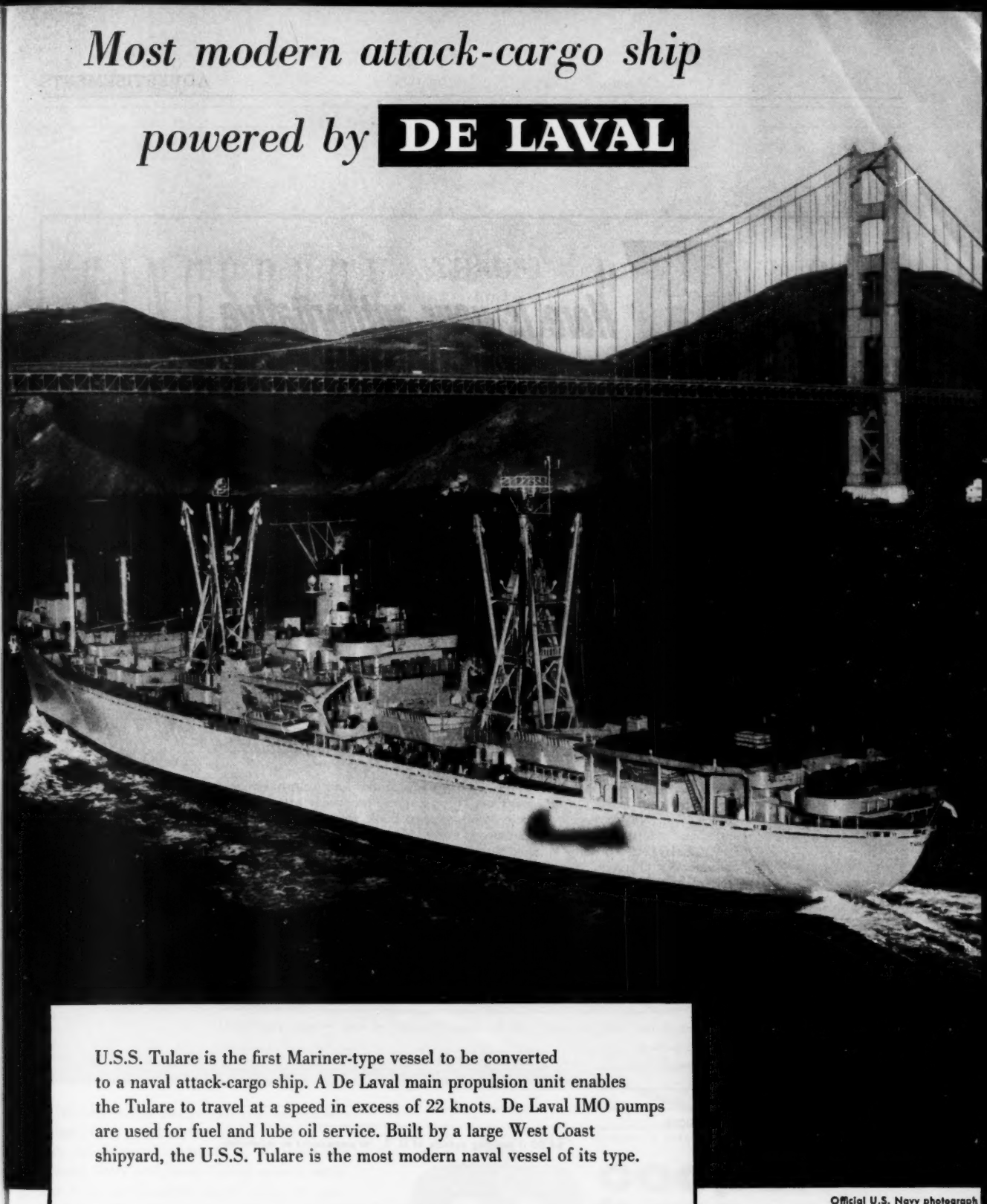

U.S.S. Tulare is the first Mariner-type vessel to be converted to a naval attack-cargo ship. A De Laval main propulsion unit enables the Tulare to travel at a speed in excess of 22 knots. De Laval IMO pumps are used for fuel and lube oil service. Built by a large West Coast shipyard, the U.S.S. Tulare is the most modern naval vessel of its type.

Official U.S. Navy photograph

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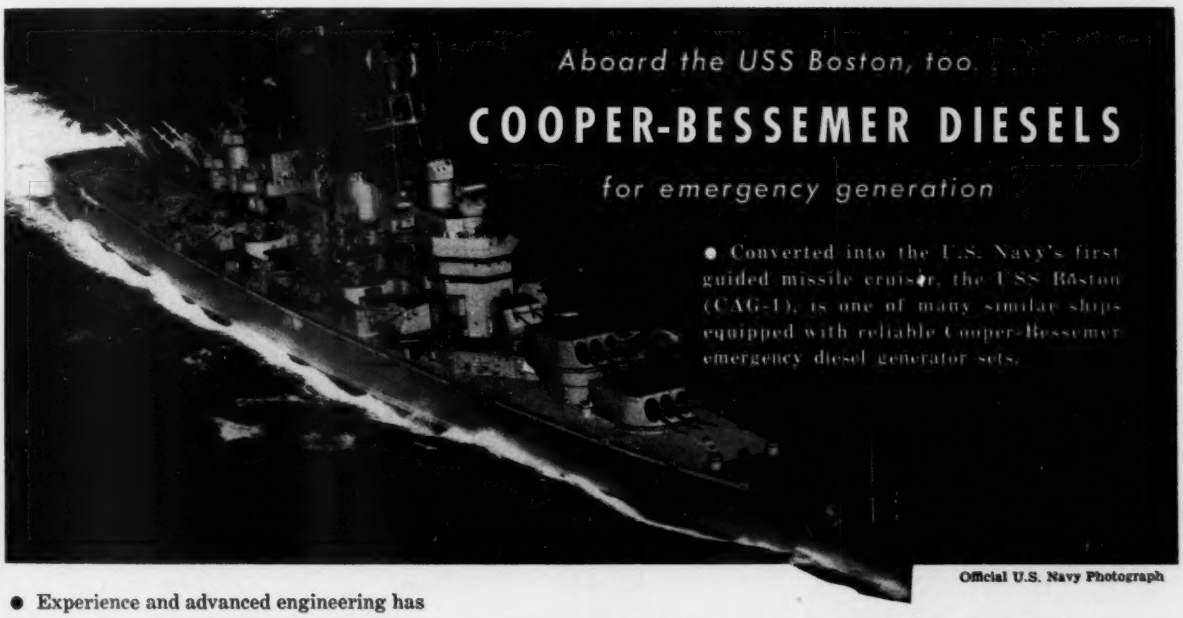
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U.S.I. CHEMICAL NEWS

A Series for Chemists and Executives of the Solvents and Chemical Consuming Industries

Greenleaf to Handle Market Development of Zirconium And Titanium for U.S.I.

William C. Greenleaf has been named Manager of Metals Development for U.S.I. and will be responsible for market development and sales of zirconium and titanium sponge, to be produced from U.S.I.'s two new plants now being built in Ashtabula, Ohio.

A recognized authority in the field of zirconium and titanium, Mr. Greenleaf presented three papers during the 1955 Atomic Industrial Forum Zirconium Program, describing (1) melting of zirconium, (2) fabrication of zirconium, and (3) zirconium mill products and prices. He also conceived and developed processes now in general use for producing both wide-sheet and flat-bar titanium and zirconium by continuous strip-mill techniques.

Faye Named Manager of Sodium Product Sales

Martin Faye has been named Manager of Sodium Product Sales for U.S.I. and will be responsible for coordinating sales and sales promotional activities for metallic sodium, "U.S.I. Isosebacic" acid and related products.

Mr. Faye joined the U.S.I.-National Distillers organization in 1952 in the Market Research and Development Department.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing the Editor, U.S.I. Chemical News.

A zirconium-copper alloy now available is reported to combine high electrical conductivity with good strength retention at elevated temperatures. Suggested for electrical motor commutators serving above 500°F where strength is needed. Conductivity is 95.8% of copper. **No.1193**

Titanium wire cloth is now on the market in sizes from 60 mesh to coarser grades. It is reported to be particularly suitable for filtering or screening highly corrosive materials. **No. 1197**

Zirconium and Titanium Lick Roughest Corrosion Problems

Metals to be Available at Lower Cost in Future; Provide Long-Lived Materials of Construction; Complement Each Other on Corrosion Resistance

It is now practical to fabricate equipment which is *corrosion-resistant to almost every substance encountered in industry*, by using either zirconium or titanium metal. Alloys of either metal, or possibly both, may extend the range even further.

Industrial applications of these metals have been hampered by two considerations: availability and price. Zirconium will shortly be produced at a rate sufficient to supply industrial needs, and titanium has been available to industry during the past two years. And it is expected that increased production of these metals during the next few years will result in significant price decreases.

Twelve to thirteen thousand tons of titanium were available in 1956 and present construction schedules indicate that the figure will rise substantially in 1957. U.S.I.'s new plant alone will add 5,000 tons to the annual production capacity by the end of the year. Zirconium will be on the market in quantity by mid-1957. When its new plant at Ashtabula, Ohio gets under way, U.S.I. will be able to supply 500,000 pounds or more per year to commercial users in addition to its Atomic Energy Commission commitments of 1,000,000 pounds per year.

New Metals Economical

Chemical process equipment can now be fabricated from titanium for a little over twice the price of stainless steel, and it is expected that in the future titanium equipment will be only 50-75% higher than stainless. Commercial grade zirconium equipment will probably be priced only 75-100% higher than stainless when volume production is reached.

Typical Corrosion Resistances* of Zirconium and Titanium

Corrosive Media	Metal Resistance	
	Zirconium	Titanium
Sulfuric Acid	excellent to good below 80%	good below 5%
Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

*Above data do not cover all conditions because of space limitations. Literature references may be obtained by writing the Editor, U.S.I. Chemical News, 99 Park Ave., N. Y. 16, N. Y.

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Raytheon Model 1500 radar consists of only *two* compact, readily-serviced units designed for simple installation and operation. Aboard naval vessels, fishing craft, work boats, ocean liners and yachts, Raytheon radar is logging a consistently superior record of performance and reliability.

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Friday, 3 May 1957.

Notices with application forms soon will be mailed to all members.

Rear Admiral A. G. Mumma, U.S.N.
Chief of the Bureau of Ships
PRESIDENT OF THE SOCIETY FOR 1957

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 69 FEBRUARY 1957 NUMBER 1

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SECRETARY'S NOTES

1957 Elections

The report of the Ballot Counting Committee was approved by the Council at the Joint meeting on 3 January 1957. The results were as follows:

Elected President for 1957:

Rear Admiral A. G. Mumma, U.S. Navy, Chief of The Bureau of Ships.

Elected to the Council to serve in 1957 and 1958:

Rear Admiral B. E. Manseau, U.S. Navy, Deputy Chief of The Bureau of Ships, to replace Rear Admiral Rawson Bennett, U.S. Navy, whose term had expired.

Captain E. A. Wright, U.S. Navy, Director, David Taylor Model Basin, to replace Rear Admiral R. E. Cronin, U.S. Navy, whose term had expired.

Captain J. H. Hartman, USNR, Bureau of Ships, to replace Lieutenant Commander J. W. Sawyer, USNR, whose term had expired.

Mr. John B. Armstrong, Westinghouse Co., to replace Mr. James S. Melton, whose term had expired.

The Secretary-Treasurer was reelected.

The composition of the Council for 1957 as a result of the elections is carried in the masthead above.

Seated (left to right) Mr. Arthur G. Fessenden; Rear Adm. B. E. Manseau, USN, Council 1957-1958; Comdr. E. G. Kintner, USNR, Council, 1956-1957; Capt. J. H. Hartman, USNR, Council 1957-1958; Lieut. Comdr. J. W. Sawyer, USNR, Council 1955-1956; Rear Adm. A. G. Mumma, USN, President, 1957; Capt. Peter V. Colmar, USCG, Council 1956-1957; Rear Adm. Kenneth K. Cowart, USCG, President, 1956; Mr. Thomas H. Shepard, Jr., Council 1956-1957; Capt. E. A. Wright, USN, Council 1957-1958; Rear Adm. L. V. Honsinger, USN, Council 1956-1957; Mr. John B. Armstrong, Council 1957-1958. Standing (left to right) Capt. J. E. Hamilton, USN (Ret.), Secretary-Treasurer, 1957; Mr. David B. McAulay, Chairman, 1957-1958 Ballot-Counting Committee; Capt. R. B. Madden, USN, Asst. Secretary-Treasurer, 1957; Rear Adm. R. E. Cronin, USN, Council 1955-1956; Rear Adm. Rawson Bennett, USN, Council 1955-1956; Capt. Peter Horn, USN, Council 1956-1957; Mr. James S. Melton, Council 1955-1956.

Joint Council Meeting

The 1956 Council and newly elected members assembled in a Joint Meeting at the Statler Hotel in Washington on 3 January, 1957. For the first time since the institution of this annual affair, 100 per cent attendance was attained. The photograph on page 4 is of those who attended the meeting.

Except for accepting and approving the report of the Ballot Counting Committee, the only action taken by the Council at this meeting was to reappoint Captain R. B. Madden, U.S. Navy, and Mr. Arthur G. Fessenden, to continue in 1957 as Assistant Secretary-Treasurer and Administrative Assistant, respectively.

1957 Banquet

Formal notice of the Annual Banquet which is to be held at the Hotel Statler in Washington, D.C., on Friday, 3 May, 1957, soon will be mailed to all members of the Society.

Vice Admiral E. W. Mills, U.S. Navy, Retired, has accepted the invitation of the President to be the Principal Speaker. As a former Chief of the Bureau of Ships, a past-President of the American Society of Naval Engineers, a past-President of the American Society of Naval Architects and Marine Engineers, Admiral Mills will require no introduction to most members. Admiral Mills is now President and Chairman of the Board of the Foster Wheeler Corporation.

It should be noted that certain changes in arrangements have been made. These are of some importance to those members who wish to organize parties. The most important of these changes are:

For *each* non-member guest, two members are required in the party.

The cost for each person will be $16.00. That is: the differential between members and non-members has been removed.

Each table will have 12 places instead of 10, as last year. This, of course, is the same as previous banquets at the Statler.

Society Flag

Through the generosity of Mr. Thomas E. Hughes, Ohio State President of the Navy League of the United States, Chairman of Cleveland Advising Council on Naval Affairs, the Society now possesses a very handsome flag. Mr. Hughes donated the flag to complete the symbols which a mature Society requires.

Normally this flag will hang in the Council Room at the Society Offices. It will be displayed in the Presidential Room of the Statler at the annual banquet.

Official U. S. Navy Photograph

Figure 1. Air View of United States Naval Academy.

CAPTAIN ROBERT B. MADDEN, USN

THE UNDERGRADUATE EDUCATION OF NAVAL ENGINEERS— U.S. NAVAL ACADEMY

THE AUTHOR

is Head of the Department of Marine Engineering at the United States Naval Academy. A 1933 graduate of the Academy, he completed a course in Naval Construction at Massachusetts Institute of Technology in 1938, and completed the Advanced Management Program at Harvard Graduate School of Business Administration in 1947. He was commissioned in the Construction Corps in 1936 and became an Engineering Duty (ED) officer in 1940. He is the Assistant Secretary-Treasurer of the Society.

Figure 1. Air View of United States Naval Academy.

INTRODUCTION

THE PURPOSE of this article is to describe in some detail the undergraduate educational program of the United States Naval Academy (Figure 1), emphasizing those areas of a scientific or engineering nature. The article does not include the programs at the United States Coast Guard Academy, the United States Merchant Marine Academy, the various colleges and universities with Naval Reserve Officer Training units, nor those colleges and universities which produce the civilian members of the naval engineering profession. The author does not intend to imply that the graduates of those programs are not just as much naval engineers as are the naval officer graduates of the Naval Academy; however, space and the author's lack of detailed knowledge limit the scope of this article to the Naval Academy program.

Furthermore, while other parts of the Naval Academy's program will be mentioned, the academic curriculum will be emphasized, and within the curriculum those elements most directly concerned with the engineering aspects of a naval officer's career will be given the most attention; i.e., the work of the Departments of Mathematics, Electrical Engineering and Marine Engineering.

THE NAVAL ACADEMY PROGRAM

The Naval Academy is unique in that it is the only institution in this country whose *sole* purpose is to provide *career* officers for the Naval Service. Even in this day when large inputs of commissioned officers come from other sources, these are for a large part short-term officers who stay in the Navy for their obligated periods and then leave for positions in civil life. The Naval Academy continues to produce the hard core of able and motivated career officers.

The Academy's mission is:

"Through study and practical instruction to provide the midshipmen with a basic education and knowledge of the naval profession; to develop them morally, mentally, and physically; and by precept and example to indoctrinate them with the highest ideals of duty, honor, and loyalty; in order that the Naval Service may be provided with graduates who are capable junior officers in whom have been developed the capacity and foundation for future development in mind and character leading toward a readiness to assume the highest responsibilities of citizenship and Government."

The Superintendent carries out the mission under the management or administrative control of the Chief of Naval Personnel. Under the Superintendent are:

a. The personal staff, of whom the Secretary of the Academic Board is the most important insofar as the academic features of the Naval Academy are concerned.

b. The Commandant of Midshipmen.
c. The Heads of the various academic departments, namely, Seamanship and Navigation; Ordnance and Gunnery; Marine Engineering; Aviation; Mathematics; Electrical Engineering; English, History, and Government; Foreign Languages; Physical Education; and Hygiene.
d. The Heads of other departments and supporting activities, such as the Chaplain, Public Works Officer, and Supply Officer.

The academic governing body is the Academic Board, which is composed of the Superintendent, Commandant of Midshipmen, and the Heads of all academic departments. This Board, which is recognized by law even though not established by law, prescribes the subjects and the arrangement of the course of instruction, approves the textbooks used, regulates the examinations, prescribes the scholastic entrance mental examinations, and makes recommendations to the Secretary of the Navy as to midshipmen to be discharged or turned back into a lower class because of academic deficiencies. Most of the detailed work, except the determination of which midshipmen are to be discharged or turned back, is accomplished by Standing Committees, subject, of course, to the review and approval of the entire Academic Board.

THE COMMANDANT OF MIDSHIPMEN

The Naval Academy is more than a college. It is a military school designed to develop in the midshipmen a continuing sense of responsibility, an instinctive self-discipline, an understanding of the principles of honor and integrity, and a spirit of loyalty to the Naval Service. While every officer and civilian faculty member attached to the Academy has a responsibility in this character development, the Executive Department, under the Commandant of Midshipmen, bears the major portion of this responsibility. The Commandant is responsible for the morale, welfare, military training, discipline, military aptitude development, and conduct of the Brigade of Midshipmen, in addition to the teaching of a small but important part of the academic curriculum. The routine, administration and leadership of the Brigade are exercised by the midshipmen themselves through their brigade organization, but of course this is carried out under the command of the Commandant of Midshipmen, assisted by the officers of the Executive Department. An extensive system of military watch standing and periodic assumption of duty, in ever increasing degree of responsibility as the midshipmen advance from year to year through their four-year course, helps to develop a sense of responsibility in the midshipmen.

THE CURRICULUM IN GENERAL

It has been said that the Naval Academy is "neither a university nor a training school, but a naval college, the undergraduate 'college' of the vast 'Navy University.'" Education for the naval profession cannot be attained in a four-year undergraduate program alone. This is necessary, of course, but to it must be added experience and postgraduate education, in order for an officer to develop the knowledge and judgment required for a successful naval career. The Navy is similar to most other professions, such as medicine, law, and dentistry, in that the development of experts or specialists in the field is left to postgraduate work in the Navy Postgraduate School, a large number of civilian colleges and universities, and various Service schools.

Accordingly, the emphasis at the Naval Academy is on basic education, which will be adequate to the career officer no matter what his later field of specialization may be. In addition, the so-called professional departments develop the acquisition of certain skills needed by the graduates for them to be of immediate value to the Fleet as junior officers, but even here the emphasis is on the fundamental principles involved. This providing of a basic education plus professional knowledge is in accordance with the Academy's mission, as previously quoted.

Compared with the usual college education, the most significant characteristic of the Naval Academy's curriculum is its integration. Integration can be accomplished to a maximum extent only where there is a fixed curriculum. The Academy does not *offer* courses, but *prescribes* courses which are valuable not only by themselves but in relationship to all other courses. Not only are the courses within each academic department carefully arranged for progressive and logical development, but the work of all departments is integrated with the view of taking advantage of numerous opportunities for mutual support. This subject of integration will be discussed in more detail later in this article.

One further very important aspect of the fixed nature of the Naval Academy's curriculum is that it provides a common basis of understanding and thus a cohesive force for career naval officers. The degree of mutual understanding among such officers, regardless of specialty, is due to a very great extent to their common basic undergraduate education.

THE COMPONENTS OF THE CURRICULUM

The curriculum for the four academic years totals 156 semester hours of college work, and leads to a degree of Bachelor of Science. It is not "B.S. in Electrical Engineering," nor "B.S. in Mechanical Engineering," because, as has been previously stated, the Naval Academy is not interested in providing specialization in those or any other fields.

For those readers not familiar with the term "semester hour," a brief explanation appears to be in order. One semester hour is equivalent to one hour of recitation per week for an entire term, or to two hours of laboratory or other practical work per week for an entire term. For example, if in a given department the midshipmen of a certain class have 3 hours of recitation and one 2-hour laboratory period per week, that would amount to 4 semester hours (3 for the recitations and 1 for the laboratory work). Then, if they had the same time assignment the next term, there would be 4 more semester hours involved. Recitations are worth twice as much as laboratory periods in this count, because for

each recitation period there is an equivalent study period. This, of course, is neither necessary nor practicable for laboratories or drills.

The 156 semester hours can be divided into four basic areas as shown in the "pie chart," Figure 2. This chart reflects academic year work only, i.e., no summer drills nor cruises are included. The social-humanistic, scientific - engineering, and physical education areas add up to 119 semester hours. The average college course leading to a degree of Bachelor of Arts, or of Bachelor of Science in general engineering, requires the completion of about 125 semester hours of work in these three areas. Hence it is evident that basic education receives substantially the same attention at the Academy as it does elsewhere. In effect, no part of it is sacrificed to provide the midshipmen with 37 semester hours of military-professional subjects; instead the latter are simply added on, bringing the total to 156 semester hours.

For specialized engineering degrees, such as Bachelor of Science in Electrical Engineering, or Bachelor of Science in Mechanical Engineering, a fair average requirement of colleges is some 135 semester hours. But the detailed electrical or mechanical engineering subjects included in such courses might very well be compared with the Academy's military-professional subjects, because, after all, the midshipmen are "specializing" in becoming professional naval officers. But even with this comparison, the midshipmen are required to take, over the four-year span, about 20 semester hours more than the engineering specialists in other colleges. The fixed curriculum and the prescribed routine are the reasons why such a heavy academic load can be imposed on the midshipmen.

Over and beyond this comparison of semester hours, one should not lose sight of the fact that the academic year at the Academy is longer than in most, if not all, civilian colleges. Over the four years the midshipmen have one 19-week term and seven 17-week terms. These are weeks of *recitations*, and do *not* include the summer programs, leave periods, June Week, nor one week of examinations at the end of each term. It should be noted that a longer term does not increase the semester hour credit; it merely means that, for the same semester hour count,

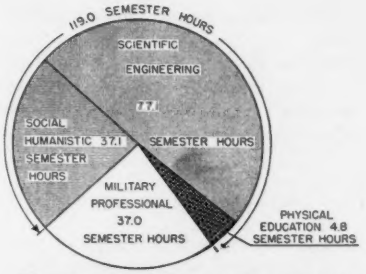

Figure 2. Breakdown of Naval Academy Curriculum into Four Basic Areas.

more hours of recitation are involved.

The 156 semester hour curriculum is based upon a 39 hour week, that is, five 7-hour days plus 4 hours each Saturday morning. During each working day, for each hour of recitation (but not for laboratories or drills) there is an equivalent hour of study (in addition, during each evening, six evenings per week, there is a compulsory 2-hour study period). All this means that the schedule is a full one, and without increasing the 39 hour week, nothing can be added to the curriculum without removing something else that is allotted an equal amount of time. And the 39 hour week could not be extended without detriment to the extracurricular program, to be described later.

THE CURRICULUM BY YEARS

Figure 3 is a building block portrayal of the curriculum, breaking it down by years and by departments or subjects, with the latter being "cross-hatched" in general accordance with the basic areas to which they belong. There are some exceptions to this, e.g. meteorology, taught by the Department of Aviation, is actually a scientific-engineering subject; on the other hand about one-third of Naval Machinery and about one-half of Naval Construction and Ship Stability are considered to be military-professional in character. To refrain from overcomplicating the chart these exceptions are not shown.

The frontal dimension of each of the blocks is commensurate with the number of *contact* hours allotted to the subject or department in question. Contact hours are used instead of semester hours simply because if the latter were used, some of the blocks representing practical drills, such as seamanship or infantry drills, would be too small to be adequately

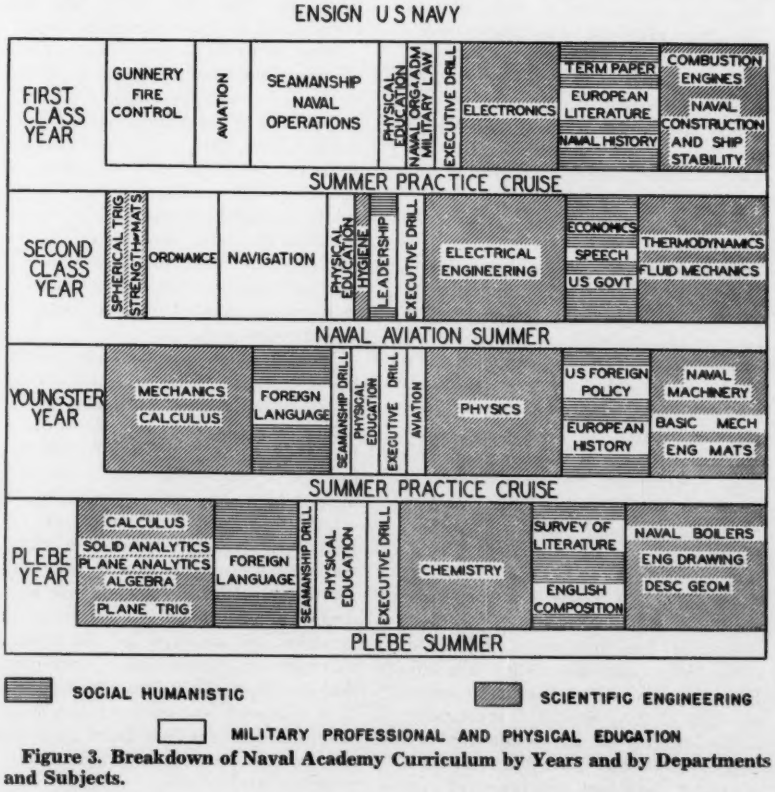

Figure 3. Breakdown of Naval Academy Curriculum by Years and by Departments and Subjects.

portrayed. In this connection laboratory periods and other practical work are included on the chart, along with recitations, but the blocks do not include summer drills nor cruises. The summers are indicated merely to separate the academic years.

It will be noted that Plebe Year (a Plebe is a Freshman in collegiate parlance) is slightly longer than the other three years. This is because the Plebes start their academic year two weeks before the other three classes in Mathematics and Marine Engineering, and one week earlier in the remaining departments.

SOCIAL-HUMANISTIC AREA

Department of English, History, and Government. This department teaches a full four year course, as shown in the blocks near the right hand side of Figure 3. Recognizing the value to a naval officer of the study of oral and written composition, literature, and the social sciences, the aim of this department (familiarly known to the midshipmen as the "Bull" Department) is to develop in the midshipman skill in the art of communication and well informed knowledge on the political, social, and intellectual world about them.

During Plebe Year the midshipmen study Composition and Literature. During the first term the emphasis is on oral and written composition, with the basic reading materials being taken from American literature. The second term emphasizes the formation of standards of literary judgment, with basic materials drawn from English literature, but with continued practice in both oral and written composition. This Plebe Year course is substantially the same as that given in freshman year at most colleges in this country.

The first term of Youngster Year (a Youngster corresponds to the college sophomore) encompasses Modern European History, that is, from 1815 to the present time. In this course the midshipmen acquire an appreciation of the values of western civilization: the basic freedoms (speech, press, assembly), and the responsibilities of individuals in a democratic society. U.S. Foreign Policy, undertaken during the second term, includes the study of geography and national power, an introduction to the fundamental principles of international law, the conduct of U.S. foreign relations, and the history of U.S. foreign policy.

During the first term of Second Class Year, corresponding to the collegiate junior year, this department teaches United States Government, a description of the structure and processes of our constitutional government and an analysis of the forces making our government what it is. This is followed the second term by a course in Economics, with emphasis on the economics of national security, i.e., government fiscal and monetary policies. Also included is a study of personal finances, to help the midshipmen understand more of the problems of saving and investing. Speech, or public speaking, is also studied this term.

The final or First Class Year starts with a course in Naval History, i.e., a study of world history from the point of view of sea power, and its influence on the rise and fall of nations. The major portion of this course is devoted to the development since 1900 of the surface, air, and underwater components of naval doctrines. In Advanced Composition and Literature each instructor establishes a theme, such as "Good and Evil" or "The Individual and Society," and he then selects textbooks (about 5 to 9 books from a panel of about 100 literary classics) which he believes will best attain the development of that theme. Also during First Class Year each midshipman writes a term or research paper of 3,000 to 5,000 words in length, based upon historical research, in which he combines the knowledge of history and the skill in the use of the English language that he has been acquiring during the four years in this department.

Mention has been made of the Speech course Second Class Year, which refers to 8 to 10 hours of formal classroom instruction. Actually the Department of English, History and Government places a great deal of emphasis on public speaking or effective speaking throughout the four year course. About ten classroom hours are devoted to this subject during Plebe Year; during Second Class Summer seven one-hour sessions are devoted to the fundamentals of conference procedures and parliamentary law; during the U.S. Government course each midshipman delivers four brief speeches on current events related to the course; and finally, during First Class Year, each midshipman delivers three after-dinner speeches under conditions as nearly realistic as it is possible to make them. These after-dinner speeches are given following formal dinners in special rooms in Bancroft Hall adjacent to the Messhall. In addition to all of the formal instruction in effective speaking, there are many extracurricular opportunities for the midshipmen, for example, in the activities of the Foreign Relations Club, the Political Economy Club, the Masqueraders (a dramatic club), and the Forensic Activity.

One further item regarding the program of the Department of English, History, and Government should be mentioned. Each year about eight evening lectures on foreign affairs and the liberal arts are scheduled for the First Class. The lecturers are distinguished scholars, specialists in government service, authors, journalists, and critics. These lectures assist the student in fitting together the knowledge he has attained, and the application of this knowledge to future understanding and policy.

Department of Foreign Languages. Each midshipman studies a foreign language for two years—the first two years of his stay at the Naval Academy—choosing one of six languages: French, Spanish, German, Portuguese, Russian, or Italian. This is the one and only elective in the entire curriculum. Year after year the percentage of each entering class taking each of these languages runs about as follows: 37-38% study Spanish, 25-27% study French, 12-13% study German, 10-11% study Russian, 6-7% study Portuguese, and 6-7% study Italian. Company and room assignments in Bancroft Hall (the midshipmen's dormitory) are according to language assignments: i.e., all the midshipmen in each room, varying from two to five in a room, are studying the same foreign language.

The objective of this department (known to the midshipmen as the "Dago" Department) is to provide

every midshipman with a working knowledge of one foreign language, and, to the greatest extent possible, to acquaint him with the geography, the customs, the history, the literature, and the economic and political institutions of the people whose language he is studying. The conversational approach is emphasized, voice recordings and special conversation texts being two of the methods used to accomplish this. Good pronunciation and intonation, correct reading habits, and development of a capacity for thinking and speaking accurately in the language are stressed.

In addition to the regular courses, advanced courses in French and Spanish are given to those midshipmen who have had at least two previous years of one of these languages, who show the necessary proficiency in oral and written placement tests, and who volunteer for the advanced course. In the first year of these advanced courses the midshipmen cover the material included in the entire two year course for the regular language courses; during the second year they are able to delve further into the language and obtain a fluent, all-around working knowledge of it. These midshipmen are thus prepared to qualify as translators or interpreters.

Each year a small number of individuals from the Philippines, from South American Republics, and even from some European countries (there are two Belgian boys in the Class of 1959) enter the Naval Academy as midshipmen. For those in need of further training in the English language, "reverse" Portuguese, Spanish or French is given—otherwise these individuals take a foreign language other than their native tongue.

There are two extracurricular features that may enhance a midshipman's foreign language capabilities. The summer cruises to foreign ports provide an opportunity to use the language and to obtain a better understanding of the people; but, of course, the value thus received depends upon the language being studied and the countries visited. In addition, there are extracurricular foreign language clubs for each of the six languages. All of the club activities are conducted in the language, and quite often diplomatic or military personnel from the countries concerned are invited to the Academy to address the clubs.

Executive Department. As has been briefly mentioned earlier, the Executive Department, under the Commandant of Midshipmen, is also involved in the academic curriculum. During Second Class Year this department teaches a course in Naval Leadership, quite properly classified as a social-humanistic subject, and represented by a comparatively small block in the middle of Second Class Year in Figure 3. This, it should be noted, is merely the formal classroom phase of the study of leadership—during his entire four years at the Academy each midshipman is being inculcated day by day with the principles of sound leadership. The course in Naval Leadership has a direct and immediate application to the duties of upper classmen within the organization of the Brigade and that is why it is placed in the curriculum during Second Class Year.

Naval Leadership is essentially a study of recognized authorities on leadership psychology and case studies of actual problems confronting a junior officer in the Fleet today. The first eight hours are devoted to the psychology of social behavior as it is related to effective leadership. Then approximately 25 hours are devoted to presenting leadership in the precept and example area through the medium of typical case studies. These case studies are taken from actual situations; they involve problems which are met by midshipmen and junior officers in dealing with naval and civilian personnel. As is typical of the case study method of instruction, the course does not furnish all the answers; rather it channels the thinking into effective areas, highlighting many basic truisms concerning the responsibilities of leadership.

MILITARY-PROFESSIONAL AREA

General. Four departments—Ordnance and Gunnery, Seamanship and Navigation, Aviation, and Executive—are the so-called "professional" departments. In addition, part of the Naval Machinery course and of the Naval Construction and Ship Stability course are classified as military-professional, but these will be discussed under the program of the Department of Marine Engineering.

Although the work of the professional departments is not classified as scientific-engineering, there is considerably more "engineering" in their courses than many outsiders believe. Those readers who were "exposed" to these professional courses about 15 years ago would be surprised at how the emphasis has shifted from the "trade-school" or "hardware" approach to an engineering approach. Throughout, the emphasis is undeniably on the theory or fundamental principles involved, rather than on the construction or operation of pieces of equipment.

One further point about the military-professional area—most of it is placed in the last two years of the curriculum. During Plebe and Youngster Years the emphasis is on basic education with what little there is in the purely naval area being limited to one short course in Basic Aviation, to part of the Naval Machinery course, and to practical drills such as infantry (Executive) and boat handling (Seamanship).

Department of Ordnance and Gunnery. The midshipmen undertake the classroom study of Ordnance and Gunnery during their last two years, although they are exposed to this subject during their previous summers. Plebe Summer they learn about the basic weapons, the rifle, the pistol, and the submachine gun, and receive considerable practice in their use on the rifle range. Then on the summer cruises they spend a portion of their time, as will be touched on later, in Gunnery Department duties.

Classroom work starts during Second Class Year with a full term of ordnance materiel, including the study of explosives, ammunition, armor, gun construction and interior ballistics, gun and turret assemblies, semi-automatic weapons, automatic weapons including aircraft weapons, rockets, torpedoes, mines and anti-submarine warfare weapons. During the second term this department teaches an introduction to exterior ballistics, and then concentrates on the surface fire control problem and main battery systems.

Gunnery fire control is emphasized during First Class Year with particular emphasis being given to anti-aircraft and anti-submarine fire control systems. In addition, aviation fire control systems, naval gunfire support, Special Weapons,

and rocket and missile control are covered.

Supporting the classroom work both years are one or two hours per week of practical drills in which various types of gunnery and fire control problems are solved on a competitive basis by groups of midshipmen. The equipment used in these drills is unique, for an academic institution, in both quality and size. To mention but a few examples, there are an integrated gunfire control system combining three separate systems, an excellent naval gunfire support trainer, a low altitude bombing trainer, and a complete antisubmarine warfare trainer.

Department of Seamanship and Navigation. The course in what is known to the midshipmen as the "Seamo" Department is conducted in two phases. The first phase covers the first two years at the Academy and is limited to practical drills held both during the summers and during the academic years. The midshipmen learn boat nomenclature, handling boats under oars, sailing, principles and applications of Rules of the Road, lookout duties, chart usage and signaling.

The second phase covers Second Class and First Class Years and includes both academic classroom work and practical drills. Second Class Year is mainly devoted to the study of Navigation, including terrestial, celestial and electronic navigation, aerial navigation, and nautical astronomy. During the last year the course is devoted to Seamanship and Naval Operations. Included are the role of the Combat Information Center (CIC), naval communications, shiphandling, some naval aspects of International Law, basic naval tactics, and all phases of naval operations, including air, surface and anti-submarine warfare. During both years the practical drills are closely integrated with classroom instruction, and include shiphandling, CIC drills, visual and radar piloting, Loran, navigation and tactics.

Like many other departments, the Department of Seamanship and Navigation has extensive instructional equipment for the various drills. In addition to a large number of various types of boats and craft (cutters, knockabouts, dinghies, yawls, whaleboats and YP's), there are four complete CIC installations, an emergency shiphandling trainer, a Loran trainer, and a Spitz planetarium.

Department of Aviation. The Naval Academy does not train midshipmen to become aviators. Even though between Second Class Summer and practical drills during First Class Year each midshipman obtains approximately eight flights in the N3N seaplane and two flights in the UF amphibian aircraft, he is not permitted to solo at any time. These flights introduce him to the sensations of flight, to the control of aircraft, and to air operations and procedures; but flight training itself is taken up, if he desires, subsequent to graduation.

The aim of the Department of Aviation is to provide the midshipmen, by means of classroom work and drills, with those fundamentals of aviation which every naval officer should know, and to give him an understanding of the uses and potentialities of naval air power.

Classroom work begins during the last half of the second term of Youngster Year, with 17 classroom hours in Basic Aviation. This course was first introduced into the curriculum last year in order to provide the midshipmen with some theoretical or fundamental background for the practical aviation work of Second Class Summer. Then during the first term of First Class Year, this department teaches a course in Air Operations, i.e., theory of flight and flight tactics, with emphasis on the operation of aircraft in coordination with other naval elements. During the second term Meteorology is studied. As has been mentioned earlier, this is a scientific-engineering subject.

Executive Department. Mention has already been made of the course in Leadership taught by the Executive Department. This department teaches two other courses, both during the final year. During the first term Naval Organization and Administration is taught; this includes the command structure of the Department of Defense, Department of the Navy, and fleet commands, Navy Regulations, and the duties of a division officer. During the second term, in Military Law, the midshipmen study the Uniform Code of Military Justice, and the Manual for Courts-Martial, with particular emphasis on those phases of military law most likely to be encountered by a junior officer.

PHYSICAL EDUCATION AREA

This area reflects the work of a single department, the Department of Physical Education, which conducts a broad, integrated program over the entire four-year curriculum. This program is intended to develop the strength, endurance, agility, physical skill and competitive spirit of the midshipmen, and can be roughly divided into six phases:

Survival (swimming).

Personal defense (boxing, wrestling, hand-to-hand).

Physical development (gymnastics, posture, personal exercise).

Athletic administration (organizing, coaching and conducting service athletic programs).

Recreational sports (golf, tennis, handball, squash, badminton, volleyball).

Development of moral and physical courage, group loyalty and fair play.

It should be noted that this program is compulsory and not a part of varsity athletics. In addition, each midshipman is tested for overall physical development and is given extra training as necessary to strengthen specific weaknesses.

SCIENTIFIC-ENGINEERING AREA

Included in this area are the work of the Departments of Mathematics, Electrical Engineering and Marine Engineering, the Department of Hygiene, and the Meteorology course which, as already mentioned, is taught by the Department of Aviation. Because of the primary importance of the work of the first three departments to the education of naval engineers, they will be described separately and in greater detail.

Department of Hygiene. During Second Class Year the midshipmen have eight classroom hours and are given eight lectures in Hygiene, or biological science. It may be of interest to note that this is the one and only course in the entire curriculum which is made mandatory by law of the Congress of the United States. The course covers the human body as a functioning machine, the care, upkeep and maintenance of this human machine, and the environment in which this machine must operate. Included in the latter are aviation medicine, underwater activity such as submarine work and diving, and the medical aspects of atomic, biological and chemical warfare.

DEPARTMENT OF MATHEMATICS

The Department of Mathematics teaches mathematics, mechanics and strength of materials over a period of the first 2½ years of the four-year curriculum. Over this period the various subjects are arranged not only in a logical order from a mathematical point of view but also in the order in which they will best support their need in other courses throughout the Academy. The latter is important because, for proper understanding, the vast majority of scientific-engineering and military-professional subjects require a sound knowledge of mathematics.

The midshipmen are given an understanding of mathematical tools and the method of using them, and then apply this knowledge to the solution of physical problems. Thus the Department of Mathematics does two things: first, it provides a facility in performing those mathematical operations most frequently used together with an understanding of the mathematical concepts behind these operations; second, it develops the midshipman's ability to set up physical problems in mathematical language, to solve them, and to interpret the results.

In this department the midshipmen have 5 classroom hours per week during the entire Plebe and Youngster Years, and 3 hours a week during the first term of Second Class Year. This frequency of recitations is considerably higher than in most other departments.

During Plebe Year the subjects covered are Plane Trigonometry, College Algebra, Plane and Solid Analytic Geometry and the first half of Calculus. Plane Trigonometry takes up 40 hours and was placed in the course about seven years ago. This was brought about by the deletion of this subject as a requirement for entrance to the Academy, since the number of high school graduates who had studied trigonometry had dwindled alarmingly. The College Algebra coverage is very brief, totalling only 16 hours, and covering inequalities, complex numbers and the theory of equations. Thirty-nine hours are devoted to Plane Analytic Geometry and 14 hours to Solid Analytic Geometry. Then the Plebe Year course winds up with 71 hours of Calculus.

Youngster Year in this department includes a continuation of Differential and Integral Calculus, Differential Equations, and Analytical and Applied Mechanics, with 70 hours of Calculus, 15 hours of Differential Equations, and 85 hours of Mechanics.

In Second Class Year the midshipmen are taught Spherical Trigonometry and Strength of Materials. The former is placed in the curriculum at this particular point, instead of immediately following Plane Trigonometry in Plebe Year, in order best to support the study of celestial navigation in the Department of Seamanship and Navigation. Prior to the current academic year (1956-57), 20 hours were devoted to the subject, and 31 hours to Strength of Materials. Because many individuals have raised the question of just how important the study of Spherical Trigonometry is to an understanding of Navigation, this year the number of hours has been reduced to 14, on a trial basis, with the number of hours in Strength of Materials increased to 37. If, after this year, a small further reduction can be made in Spherical Trigonometry, the Department of Mathematics plans to reinstate a course in some of the fundamentals of statistical analysis involving permutations, combinations, and probability.

DEPARTMENT OF ELECTRICAL ENGINEERING

Fifteen to twenty years ago this was known to the midshipmen as the "Juice" Department; now it is called the "Skinny" Department. But in at least one respect it hasn't changed—it still teaches a full four-year course, with a full year each of the basic sciences of chemistry and physics, followed by a year of electrical engineering and one of electronics. The first two form necessary background for all engineering subjects and most of the professional subjects taught at the Academy.

Chemistry. The Plebe Chemistry course is a general Chemistry course quite similar to that taught in most engineering colleges; in fact, a standard college textbook is used. It includes a study of the fundamentals of chemical theory and of the chemical properties of metals and nonmetallic elements. The subject starts with the laws of chemical change and atomic structure, and ends with qualitative analysis by the semimicro technique. Included are such items as radioactivity and nuclear reactors, and such practical naval

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Figure 4. Single-Section Chemistry Laboratory in Department of Electrical Engineering.

applications as corrosion, water treatment, and explosives.

Chemistry is taught by a combination of three methods—the classroom recitation, the demonstration lecture to large groups, and the laboratory. There are 92 hours of recitations and lectures, with the latter occupying a relatively small proportion of this time. Sixty-eight hours are assigned to laboratory work, i.e., one 2-hour laboratory period each week of the year. The laboratories, one of which is shown in Figure 4, are single-section laboratories, i.e., they are capable of holding no more than 18 students from a single recitation section. The classroom instructor for each recitation section likewise conducts the laboratory work for that section, and all work is accomplished by the student on an individual, rather than a team or group basis.

Physics. The Physics course is also one of general physics, and here, too, a standard college textbook is used. The course includes four basic areas, (1) mechanics, (2) heat, (3) wave motion, sound and light, and (4) electricity and magnetism, and of these the first, mechanics, occupies most of the first term. Included also is a limited coverage of atomic and nuclear physics, as well as the theory of the gyroscope and optical instruments.

In Physics 98 hours are devoted to recitations and lectures, and 66 hours to laboratories. Like the Plebe Chemistry laboratories, those in Physics are conducted in rooms capable of holding a single recitation section of midshipmen. The demonstration lectures include much apparatus and are often used as previews or reviews of important parts of the course taught in the classrooms. Figure 5 shows Senior Professor E. W. Thomson, known to generations of Academy graduates as

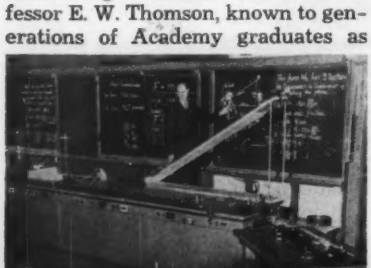

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Figure 5. Demonstration Lecture in Physics—Department of Electrical Engineering.

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Figure 6. Electrical Engineering Laboratory in Department of Electrical Engineering.

"Slip-Stick Willie," and who did practically all of the lecturing in Physics from 1930 to 1942, giving one of his last lectures six years ago.

Electrical Engineering. Second Class Year the subject of Electrical Engineering covers both direct current and alternating current, and again a standard college text is used. This is not a "hardware" course in which pieces of shipboard electrical equipment are studied—it is a study of basic principles or fundamentals of Electrical Engineering. The subject starts with simple electric circuits, electric and magnetic fields, and the generation of electromotive forces, and then progresses through the characteristics of direct current machinery before taking up alternating current circuits and machinery.

During Second Class Year 96 hours are devoted to recitations and lectures, and 66 hours to laboratory work. The latter differs from that of the previous two years in that the work is accomplished on a group basis rather than on an individual basis. Figure 6 shows a group performing a laboratory experiment in which they are operating a motor-generator set preparatory to throwing the generator "on the line" after proper adjustments are made.

Electronics. During the final year of the curriculum the Department of Electrical Engineering teaches a course in the theory and basic principles of Electronics, emphasizing electron emission and ballastics in vacuum and gas-filled tubes, and the behavior of circuits and circuit elements over a wide range of frequencies. Microwave techniques and apparatus are included. The course ends with a discussion of radar, Loran and sonar, but even in this phase, basic theory is stressed. Because no suitable college textbook is available, a text prepared by members of the civilian faculty of this department is used.

Electronics consumes 59 classroom hours and 60 hours of laboratory work. Two views of the latter are shown in Figures 7 and 8. In Figure 7 two midshipmen are operating a transmission line apparatus, with the points of high voltage and the standing waves being shown by fluorescent tubes. The cathode-ray oscillograph is part of nearly every experiment; Figure 8 shows an experiment in the operation of the oscillograph, held early in the course to acquaint the students with this research instrument.

One unusual piece of instructional equipment used in the Electronics course is the Electronic Field Laboratory, or Sonar Barge. This barge includes listening, search and scanning sonar systems, air and surface search radars, an electronics counter measures system, teletype receivers and transmitters, and a Loran automatic HF radio transmitter.

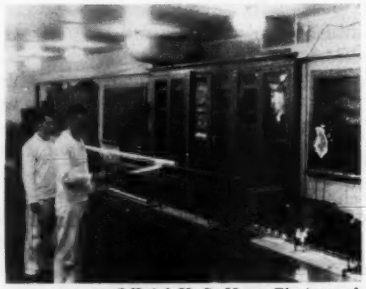

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Figure 7. Electronics Laboratory in Department of Electrical Engineering.

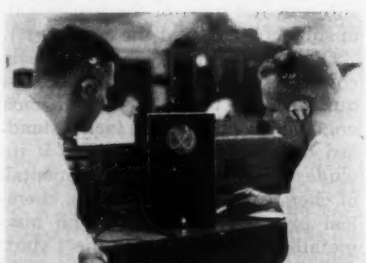

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Figure 8. Experiment in Operation of Cathode-Ray Oscillograph in Electronics Laboratory—Department of Electrical Engineering.

Use of Television. Mention has been made of some of the teaching methods used by the Department of Electrical Engineering. Another one, and one rather unique in educational circles, deserves some discussion—the use of a closed-circuit television system. Such a system was placed in operation on September 1, 1953. It consists of four camera chains: two field image orthicon camera chains, one vidicon camera chain and one film camera chain. The first three are usually used in the studio but may be taken to locations within 1,000 feet by the use of extra camera cable. By use of a microwave link, tranmissions can be made from within a range of 15 miles, and an antennaplex system permits local area TV channels to be received. Programs are sent simultaneously to standard 21-inch receivers in 19 classrooms and one lecture hall, and to a theater projection system in an auditorium. The TV spaces consist of a 480 sq. ft. studio, a 300 sq. ft. control room, and a 300 sq. ft. workshop.

Television is not used as a substitute for instructors, but as a teaching aid acting as a supplement to the instructor, by sending short programs into the classroom as *part* of the day's lesson. It is used in those cases which cannot be handled by the normal classroom instructor, or where television is much more effective than such instruction. For example, when certain complicated or bulky equipment is to be demonstrated, it would not be feasible to put such equipment in each classroom, and without television the students would have to be moved to a lecture room. For short demonstrations this would be wasteful of time and would not provide the extreme detail that the close-up shots of television can provide. Television can also be used to show many things that cannot be introduced into the classroom and which would not justify the making of a film, and to make available to a large group of students a well developed presentation which would be less effective if given by twenty or so different instructors. It is *not* used where the usual blackboard work, movies, slides or demonstrations lectures would do just as well or better.

The Department of Electrical Engineering uses television programs periodically throughout the four-year curriculum. The best results have come from programs 10 to 20 minutes in length, with occasionally one of 30-35 minutes, but never longer. Then after the TV demonstration the normal instructor-student question and answer session takes place, thus combining the two into a well-rounded period of classroom instruction.

Figure 9 shows an instructor in the TV studio demonstrating the diagram of a multivibrator circuit in the Electronics course. Figure 10 shows a classroom demonstration on the 21-inch TV receiver of the action of the transistor.

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Figure 9. Naval Academy Educational Television System Studio in Department of Electrical Engineering. A Lecture on the Multivibrator Circuit is being Transmitted into Classrooms for Inclusion in a Lesson in Electronics.

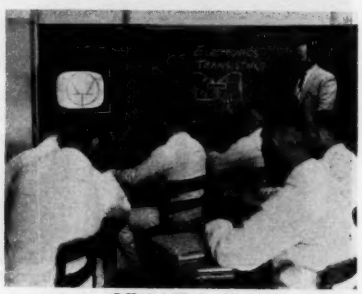

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Figure 10. Television Instruction in the Classroom in Electronics Course—Department of Electrical Engineering.

DEPARTMENT OF MARINE ENGINEERING

The Department of Marine Engineering, or the "Steam" Department as it has been known to the midshipmen for generations, teaches a full four-year general engineering course as shown in the extreme right hand blocks of Figure 3. The course includes the subjects Descriptive Geometry, Engineering Drawing, Naval Boilers, Engineering Materials, Basic Mechanisms, Naval Machinery, Fluid Mechanics, Thermodynamics, Naval Construction and Ship Stability, and Internal Combustion Engines.

The department's goal or mission is to educate midshipmen in the fundamental theories of marine engineering and its naval applications, to familiarize them with recent typical naval engineering installations, and to provide an adequate technical foundation on which further study may be satisfactorily based. Throughout, the emphasis is on basic principles rather than on special applications that may be here today and gone tomorrow.

Instruction consists of classroom recitations, drawing room work, a relatively small number of lectures, and laboratory or other practical work. The last may be classified under three general headings: (1) practical instruction in basic shop practices (since most of this occurs during Plebe Summer it will be taken up later along with the other summer programs), (2) laboratory exercises in Engineering Materials, Fluid Mechanics, and Thermodynamics, demonstrating the physical properties of metals, gases and fluids, and (3) laboratory drills concerned with the principles, construction, operating procedures, potentialities and limitations of machinery installations and of the ship as an entity. These laboratory exercises generally follow within a day or two those classroom periods in which the subject under question has been studied and discussed, and hence assist in fixing in the student's mind the fundamental principles involved.

Engineering Drawing and Descriptive Geometry. The objective of this subject is to develop a good working knowledge of the "language of the engineer." The students are not being taught to be draftsmen—in fact some "old-timers" would probably be surprised to learn the extent to which free-hand sketching is employed, and more surprised to learn that the use of ink is limited to one rather simple plate. In fact, the midshipmen actually have a pen in hand for a total of only 2 hours in the entire course. The course is intended to develop the constructive imagination and perceptive ability needed to think in three dimensions, or in other words to develop the ability to form a mental picture and

the skill to record accurately, rapidly, neatly and legibly the visualized impression.

The midshipmen take this subject for three-quarters of Plebe Year, i.e., a term and a half. Three two-hour sessions are devoted to it each week for a total of 160 hours. No outside study is required; instead the first 15-20 minutes period of each two-hour session is set aside for the midshipmen to read and study the textbook assignment. During the next 20-25 minutes lectures, with questions and answers, are given to each section of 14 or 15 students by the instructor assigned to that section. The remaining time, approximately one hour and ten minutes, is then spent by the midshipmen on the drawing board. Figure 11 depicts this third phase.

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Figure 11. An Engineering Drawing Section in the Department of Marine Engineering.

Naval Boilers. To end up the year in the "Steam" Department the Plebes have nine weeks of Naval Boilers, with two hours of classroom work and one two-hour laboratory period per week. This totals 18 classroom hours and 18 laboratory hours. The primary objective of the course is to familiarize the students with the basic principles upon which a boiler operates and with the types of naval boilers, including accessories and fittings, with which they are most likely to come in contact in the Fleet. The course also teaches the fundamentals of the basic steam cycle, as well as boiler water, feed water, and fuel oil systems. A secondary yet immediate objective of the course is to familiarize the midshipmen with one major piece of shipboard machinery prior to their embarking on their first summer cruise. The text is one specially written for this course by a member of the department's faculty.

The boiler laboratory is composed of a full-scale, sectionalized boiler, together with a group of boiler auxiliaries and smaller models of other types of boilers. The sectionalized boiler (Figure 12) is a Babcock and Wilcox, double cased, divided furnace, single uptake, express type boiler, of the type installed in the DD445 class of destroyers. It is fairly safe to say that the midshipmen will probably never see so much of a boiler again in their entire naval careers.

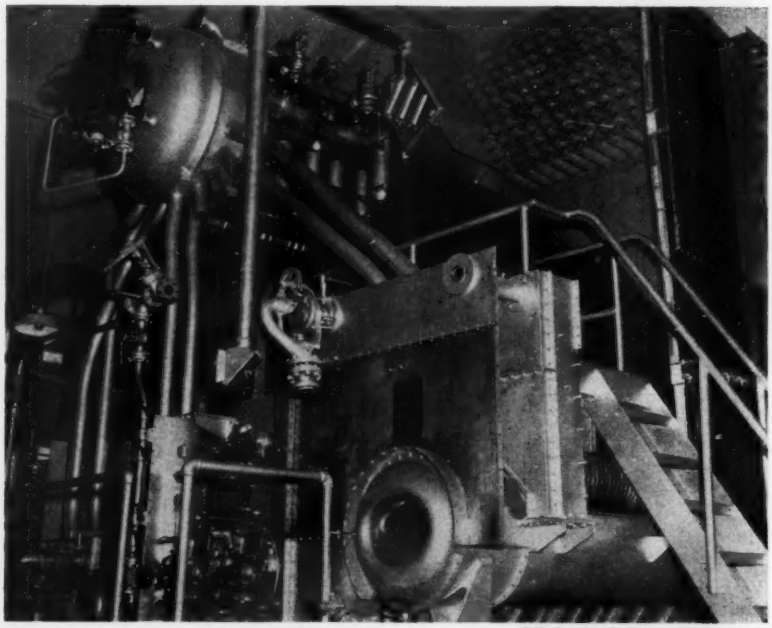

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Figure 12. Sectionalized DD445 Class Babcock and Wilcox Boiler in Boiler Laboratory—Department of Marine Engineering.

The auxiliary equipment includes a fire and bilge pump, fuel oil booster and transfer pump, fuel oil service pumps, fuel oil meter, fuel oil strainer, main steam stop valve, combined feed stop and check valve, safety valves, soot blower, fuel oil burner, and forced draft blower. All are sectionalized so that the basic operational features are plainly visible, and the flow paths of fuel oil between the large boiler and its auxiliaries are indicated by inlays in the asphalt tile deck covering.

Engineering Materials. For the first eight weeks of Youngster Year the department teaches Engineering Materials. The objective of this course is to give the student an understanding of the structure, properties and uses of metals, hence to provide a basis for the understanding of the capabilities and limitations in practical applications aboard ships and aircraft. The course is covered in 23 classroom hours and 16 laboratory hours, with the former being divided into 8 hours of the structure and properties of metals, 5 hours of heat treating of steels, 5 hours of cast iron and non-ferrous metals, 1 hour of nuclear effects, and 4 hours of introduction and review. The laboratory work generally supports the classroom work although two hours are devoted to fuels and lubricants and two hours to non-metallic materials such as plastics, rubber and paint. The emphasis in the course is basically one of physical metallurgy rather than process metallurgy (as in the past), and for that reason a standard college textbook is being used.

The laboratory is divided into 6 rooms or "cells," all identically equipped, so that each recitation section of midshipmen has a "cell" to itself. In each cell there are installed a quenching vat (oil and water), an electric heat-treating furnace, a centrifuge, a Brinell hardness tester, a Rockwell hardness tester, a metals tensile tester, a metals impact tester, a plastic tensile tester, a plastics impact tester, and a viscosimeter. Portable testing equipment such as spark testing grinding machines, spot testers, open cup and closed cup oil testers, pour point test-

ers and microscopes of 150:1 magnification are also available.

Basic Mechanisms. The objective of the course in Basic Mechanisms is to teach the operational fundamentals of the common mechanisms encountered as individual devices, together with their many variations, combinations and interrelations as components of more complicated machines. The subject is taught the last nine weeks of the first term of Youngster Year. It consists of 23 classroom hours and 18 hours of laboratory work, with one-half the time spent on gears and gear trains, including epicyclic trains, one-fourth on the fundamentals of motion and work, and one-eighth each on linkages and rolling bodies. The laboratory periods are used for lectures and demonstrations of various types of mechanisms (using the machinery models described below), tearing down and assembling such items as a hydromatic transmission, and working various types of mechanisms problems. The textbook for the course is a new one this year, written by one of the civilian faculty members of the department and reviewed in this issue of the JOURNAL.

Naval Machinery. The entire second term of Youngster Year is spent on a course in Naval Machinery, consisting of 42 classroom hours and 17 laboratory hours. The purpose of the course is to acquaint the midshipmen with the functions and operating principles of some of the more important engineering equipment and systems found on board ship. Included are the elementary principles of turbines, their basic design features and operation, including reduction gears, shafting and bearings. This is followed and supported by a study of the various units of auxiliary machinery such as pumps, condensers, distilling plants, heaters, coolers, refrigeration equipment, anchor gear and steering gear. Two to three hours are now being devoted to nuclear ship propulsion, with special pumps, etc., for such systems being covered during the study of other auxiliary equipment. Basic engineering fundamentals are stressed throughout the course. The text is one written by members of the department's faculty.

The laboratory work supplements the classroom work through demonstrations of sectionalized machinery and scaled models of ships and of machinery spaces. The laboratory is actually the Isherwood Hall model

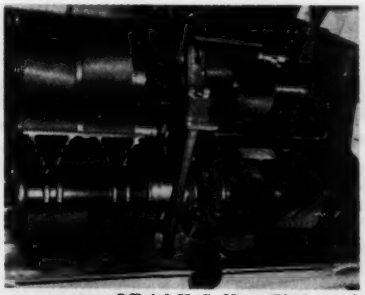

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Figure 13. Sectionalized DD445 Class Main Reduction Gears in Department of Marine Engineering.

room in which are contained the following types of equipment:

(1) The main propulsion machinery and associated auxiliary machinery from one engine room of the *Haggard* (DD555). This ship was Kamikazed near the end of World War II, and was placed out of commission in November, 1945. The one machinery plant remaining intact was removed, and is now installed in Isherwood Hall with casings lifted and equipment sectionalized to clearly show the operation of each piece. The main reduction gears are shown in Figure 13 and the 290 KW turbo-generator in Figure 14. The tie-in between the turbine and its auxiliaries is shown by various colored inlays in the asphalt tile decking—one color for feedwater, another for lubricating oil, another for air, etc.

(2) Models of machinery spaces of various type ships. Included are one each of the DD445 Class (Figure 15), the DE/FMR Class, the LST 1-490 Class and the battleship *South Dakota*. The latest additions along this line are one main machinery space and one auxiliary machinery space of the *Saratoga* (CVA60).

(3) Various ship models, generally scaled ¼ inch to the foot, ranging from the latest class of battleship and carrier down to various types of landing craft, several floating drydocks, and a ½ inch to the foot completely sectionalized model of the DD692 Class (Long Hull). These ship models are on a more-or-less permanent loan basis from the Bureau of Ships (and the Bureau of Yards and Docks in the case of the floating drydocks).

(4) Miscellaneous equipment including an operating model of a cruiser anchor windlass, an operating model of a double-ram type steering gear, a sectionalized and mechanized model of a vapor compression distilling plant, cut away models of a solo-shell, low pressure, double effect distilling plant, and of a high pressure air compressor, and an operating schematic model showing the basic operation of a nuclear ship propulsion plant.

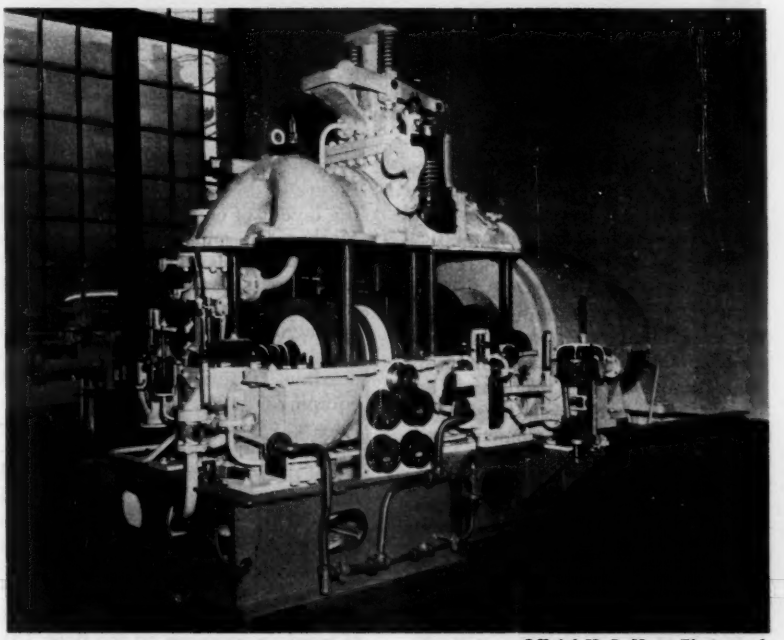

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Figure 14. DD445 Class 290 KW Turbo-Generator in Department of Marine Engineering.

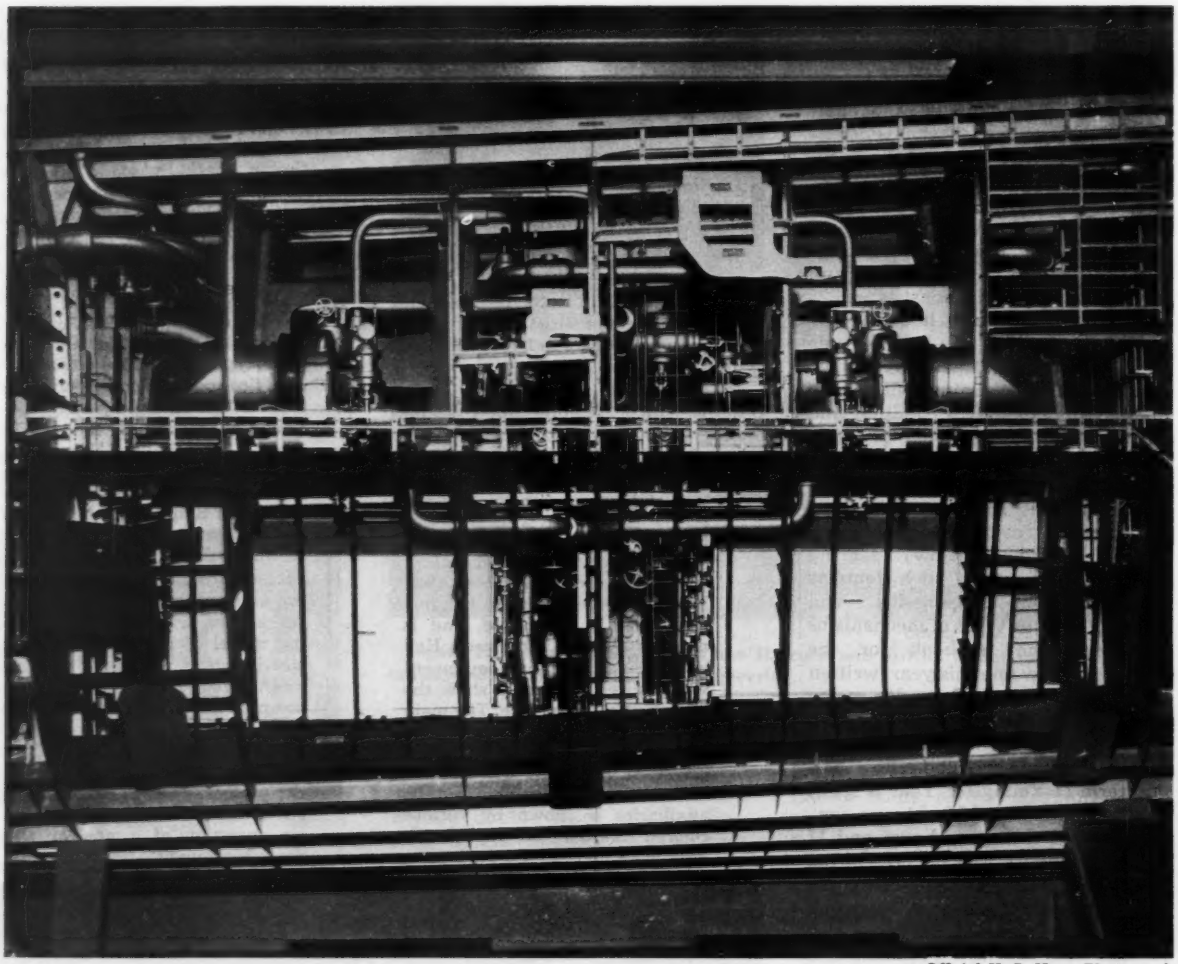

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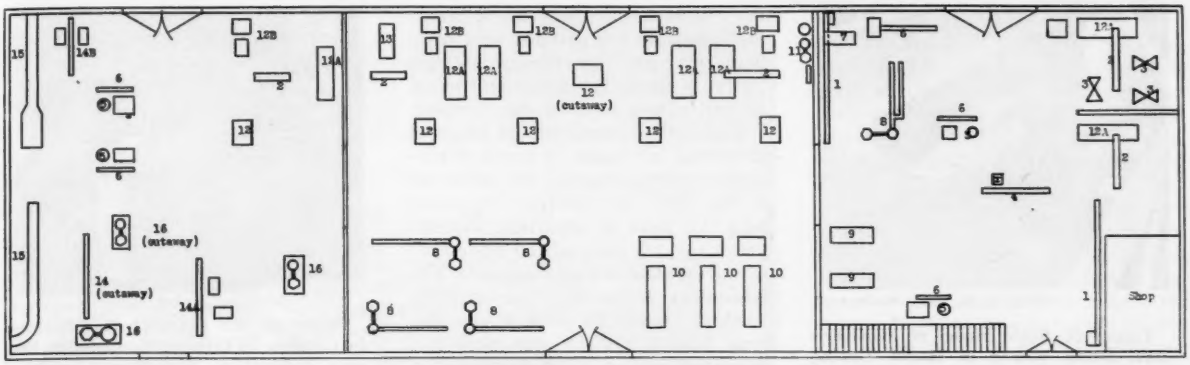
Figure 15. 1½ Inch to the Foot Scale Model of DD445 Class Machinery Spaces in Department of Marine Engineering.

Fluid Mechanics. Fluid Mechanics, the study of liquids and gases under all possible conditions of rest and motion, is taught from the analytical and logical rather than the purely empirical point of view. An attempt is made to lay a firm foundation of physical fluid flow concepts, coupled with examples of application to actual situations. The properties, behavior and energy relationships of fluids are studied with particular reference to the pumping, metering and piping of fluids. The dynamics of incompressible and compressible flow of gases including the fundamentals of aerodynamics and the special problems presented by supersonic velocities are also covered. A college text is used.

Fluid Mechanics is studied the first term of Second Class Year, there being 42 classroom hours and 34 hours of laboratory experiments. Figure 16 is a schematic diagram of the layout of equipment in the Fluid Mechanics and Thermodynamics Laboratories. It should be noted that there are several of each piece of test apparatus in order that the experiments can be performed by the midshipmen in as small groups as possible. The most important test equipment items for Fluid Mechanics are (1) air flow apparatus—for comparing the venturimeter, combined pitot tube and flow nozzle, and for investigating two dimensional flow, (2) De Laval converging-diverging nozzles—for determining the variation of pressure of a compressible fluid (steam) passing through such a nozzle, and the effect of receiver pressure on the flow, (3) wind tunnels—to measure the effect of varied air speed and angle of attack on pressure distribution over an airfoil, and to measure lift and drag forces, (4) standpipes—for calibration of circular orifice, (5) pipe friction apparatus—to determine loss coefficients of commonly used pipe fittings, and (6) centrifugal pumps—to test the performance of a 400 g.p.m. fire pump. Certain other pieces of equipment are used for demonstration rather than for experiments. These include the pipe flow demonstration to indicate transition from laminar to turbulent flow, smoke tunnels, and the propeller cavitation display (Figure 17). In the latter, a 3" propeller is turned in a plexiglass chamber filled with water. A stroboscopic light makes the moving blade appear stationary so that the cavitating flow can be inspected. The effect of static pressure on cavitation, experienced by a sub-



Item	Nomenclature	No. Installed
1.	Air Flow Apparatus	2
2.	DeLaval Nozzle	5
3.	Wind Tunnel	3
4.	Model Refrigeration System—York Trainer	1
5.	Standpipe	4
6.	Pipe Friction Apparatus	5
7.	Flow Comparison Apparatus—Laminar vs Turb.	1
8.	Centrifugal Pump	5
9.	Smoke Tunnel	2
10.	Refrigeration Systems	8*
11.	Desuperheating Station—Laboratory Steam Supply	1
12.	60 KW D.C. Turbogenerator Set	5
12A.	Condenser for 60 KW Turbogenerator Set	7
12B.	Switchboard and Rheostat for 60 KW Turbogen. Set	5
13.	Propeller Cavitation Display	1
14A.	Double Pipe Heater—Counterflow	1
14B.	Double Pipe Heater—Parallel Flow	1
15.	Unit Heater	2
16.	Two Stage Air Compressor	5*

* Some machines are located outside the laboratory in machine shop spaces.

Figure 16. Diagrammatic Arrangement of Equipment in Fluid Mechanics and Thermodynamics Laboratories—Department of Marine Engineering.

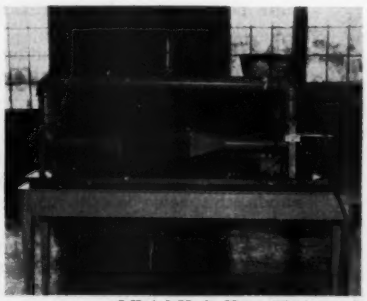


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Figure 17. Cavitation Demonstration Apparatus in Fluid Mechanics Laboratory—Department of Marine Engineering.

marine at various depths, can be demonstrated by increasing the pressure in the chamber with a small hand pump.

Thermodynamics. This study of the behavior of vapors and gases applied to various heat power requirements, i.e., the study of the basic heat laws, is taught second term of Second Class Year. There are 51 classroom hours and 34 laboratory hours. The text is written and periodically revised by faculty members of the department.

Referring to Figure 16, the important pieces of laboratory equipment are: (1) vapor compression refrigeration systems—for determining refrigeration capacity, power requirements and heat rejection rates, (2) 60 KW d.c. turbo-generator sets—for determining steam rate, heat rate, efficiency, and effect on turbine performance of excessive throttling of the steam supply and excessive exhaust pressure at the condenser, (3) condensers for the turbo-generators—for separate experiments of vapor-to-liquid heat exchanges, (4) parallel and counterflow heat exchangers — for determining heat transfer rates, (5) unit heaters—for further heat exchange experiments, and (6) air compressors—for studying energy flow in the system. Figure 18 shows one of the 60 KW turbo-generator units, and Figure 19 shows a cut-away unit. The latter is driven by an electric motor and can be turned over to show the students the operation of the turbo-generator from one end to the other. This is an excellent teaching aid in that it tends to "take the mystery out of the black box" (in this case the 'boxes' are painted aluminum, not black). A similar technique is used in the case of the air compressors, as indicated in Figure 16

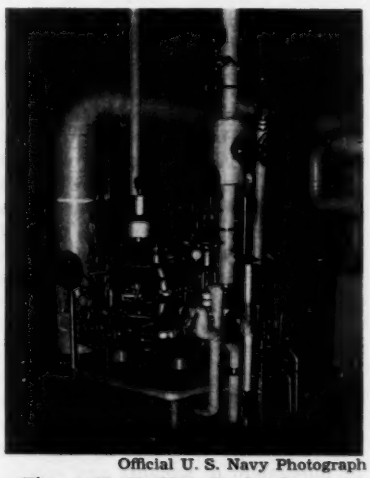

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Figure 18. 60 KW Turbo-Generator Unit in Thermodynamics Laboratory—Department of Marine Engineering.

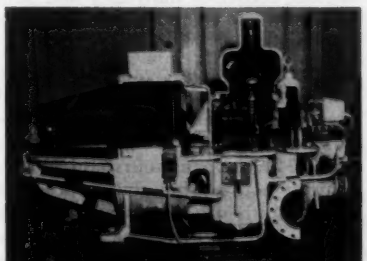

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Figure 19. Sectionalized 60 KW Turbo-Generator in Thermodynamics Laboratory—Department of Marine Engineering.

Naval Construction and Ship Stability. This course, taken the first term of First Class Year, is taught to give the midshipmen an understanding of the character and physical behavior of ships at sea. The emphasis is on the control of damaged stability and damaged structure of naval ships, but including a background of buoyancy, stability, resistance, strength and other ship characteristics. Because of the level of

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Figure 20. Scale Model of FORRESTAL Being Towed in Model Towing Tank in Naval Construction and Ship Stability Laboratory — Department of Marine Engineering.

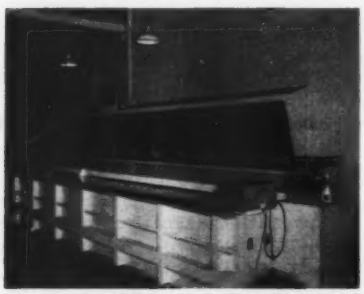

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Figure 21. General View of Model Towing Tank in Naval Construction and Ship Stability Laboratory—Department of Marine Engineering. Shows Driving Weight End and E-nut Meter for Reading Model Speeds. Model of MARINER being Towed.

Official U. S. Navy Photograph

Figure 22. Stability Model of CL46 in Towing Tank in Naval Construction and Ship Stability Laboratory—Department of Marine Engineering.

the course, no availabe naval architecture books are suitable, so a textbook prepared specifically for this course is used. The latest text is reviewed in this issue of the JOURNAL.

This course consumes 34 hours of classroom work and 34 hours of laboratory work. Some of the latter are in the form of lectures, but most take the form of analytical investigations which parallel the basic theory presented in the classroom. The laboratory includes a towing tank, 52'x6'x4', equipped with a gravity-type towing system and electronic speed calculator. The midshipmen tow scale resistance models of *Mariner* (C-4 hull), *Forrestal* (CVA59) and *Dealey* (DE1006), and compute the parent ship horsepower. Figure 20 shows the *Forrestal* model being towed; Figure 21 is a more general view of the tank with the *Mariner* model being towed.

The towing tank is also used for inclining experiments, ship-launching demonstrations, and stability exercises. Stability models of CVE 105 Class and DD 692 Class are used for static, dynamic and overall stability studies, including free surface and free communication with the sea. Figure 22 shows a model of CL 46 Class being inclined for the static stability curve. Also available is a scale model of the DE 51 Class in which all below deck compartments can be flooded by remote control through solenoid-operated sea valves controlled from a console at the side of the tank. Flooding and counter-flooding problems can by demonstrated by these means.

Other laboratory equipment includes ten 36" small metal stability models in small tanks, with stability characteristics alterable by addition or movement of weights and special internal tanks. Many other smaller devices for illustrating trim computations, center of buoyancy and ship displacement computations, etc., are also available.

Internal Combustion Engines. The final course in the Department of Marine Engineering is Internal Combustion Engines, to which are devoted 34 classroom hours and 34 laboratory hours. This course presents the basic theory, fundamental principles, and performance characteristics of the spark and compression ignition reciprocating engines, the gas turbine, jet engines, and rocket engines. In addition, several lessons are devoted to nuclear ship propulsion. This subject, however, is being shifted to Youngster Year Naval Machinery.

Official U. S. Navy Photograph

Figure 23. Air Research Gas Turbine Installation in Internal Combustion Engine Laboratory—Department of Marine Engineering.

The laboratory is divided into 6 cells, four of which are identically equipped with:

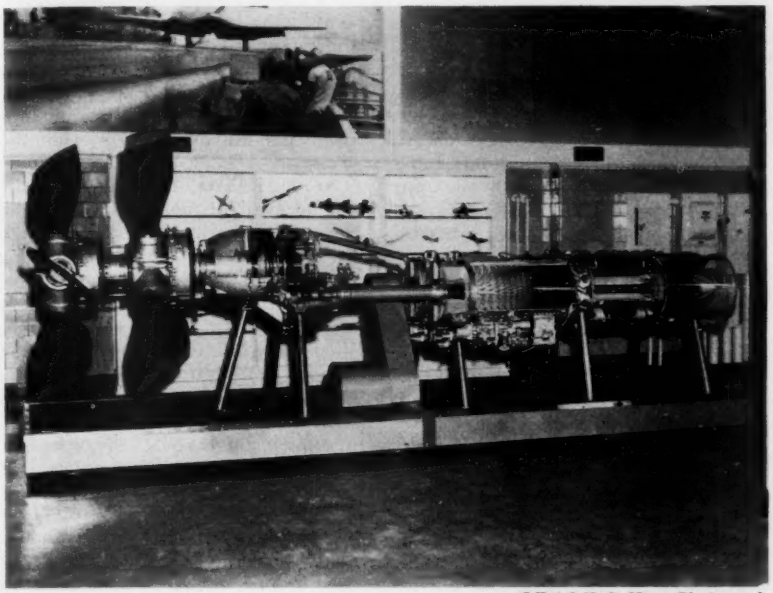
(1) One CFR spark-ignition, single cylinder, four-stroke, variable compression engine used to measure octane rating and to determine performance characteristics of spark ignition engines.

(2) One Continental spark-ignition, 4-cylinder, four-stroke engine, rated at 31 H.P. at 2400 R.P.M., and coupled to a dynamometer.

(3) One G.M. 2-71, 2 cylinder, two-stroke diesel engine, rated at 30 B.H.P. at 1200 R.P.M., used to obtain the heat balance of reciprocating engines.

(4) One Air Research gas turbine with a simple open cycle GT-2 stage centrifugal flow compressor and single stage turbine, with 40,100 R.P.M., reduction gear of 6.75:1, and maximum B.H.P. of 84 at 6,000 R.P.M. This unit, shown in Figure 23, is now being installed in each cell for use during the second term of the present academic year. It will be used to obtain typical gas turbine performance curves and information necessary for a plot of the operating cycle.

A fifth cell has the same equipment as listed above plus one CFR compression-ignition, four-stroke, variable compression engine. A dynamometer is coupled to both this and the CFR spark-ignition engine, and an oscilloscope pick-up for visual presentation of combustion phenomena is connected to the latter. Adjacent to this cell, and separated from it by a large glass "window," is an amphitheater seating about 80. A normal two-hour laboratory period starts with all the midshipmen seated in the amphitheater, and the in-



Official U. S. Navy Photograph

Figure 24. Sectionalized Allison T-40 Turbo-Prop Engine in Internal Combustion Engine Model Room—Department of Marine Engineering.

structor in the cell proper. While running through an experiment he describes his actions using a throat microphone; questions are relayed back to him via an instructor in the amphitheater equipped with a hand-microphone. This is the finest set-up known to the author for teaching or demonstrating under extremely noisy conditions. After the instructor has completed his demonstration or run-through of the experiment, the midshipmen are divided into five groups, each of which runs the experiment in one of the cells.

The sixth cell is equipped with:

(1) One CFR compression-ignition engine.
(2) Two Christie single cylinder, four-stroke, variable compression engines.
(3) One Boeing gas turbine, Model 502, similar to those installed in some minesweepers for auxiliary generators or for mine-sweeping gear. This gas turbine has been used for demonstration purposes for two years, but since only one was available no experiments could be conducted by the midshipmen. The Air Research gas turbines now being installed will correct this deficiency.

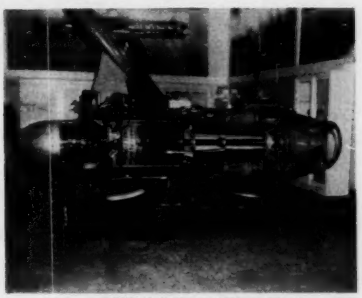
In addition to the laboratory itself the department has an elaborate internal combustion engines model room. Included are some typical ship engines and some typical aircraft engines. The former include the following completely sectionalized and electrically operated engines (all moving parts, including pistons, cams, valves, etc., operate): Fairbanks-Morse opposed-piston engine, Superior diesel, Hamilton diesel, GM-16-278A diesel, GM 16-184A Pancake diesel, GM-16-258S diesel, Gray marine diesel, GM 3-268 Diesel, Chris-Craft gasoline engine, Packard marine gasoline engine, Caterpillar diesel, and a Junkers free piston air compressor. Other ship type equipment include a sectionalized hydraulic coupling, a clear-plastic encased Wolverine plant model, and a similar model of an Elliot gas turbine plant.

The aircraft equipment include the following sectionalized and fully-operating (electrically) engines: Allison T-40 turbo-prop engine (Figure 24), GE J-47 jet engine (Figure 25), Allison J-47 jet engine, and Pratt & Whitney R-2800 gasoline engine. Other aircraft equipment include these sectionalized but non-operating units: Marquardt ram jet, McDonnell pulse jet, GE turbo-supercharger, and Aerojet JATO unit.

It should be mentioned that most of the ship units were sectionalized by the Charleston Naval Shipyard, whereas the recent aircraft engines, Figures 24 and 25, were completely sectionalized by shop personnel in the Department of Marine Engineering.

SUMMER PROGRAMS

Plebe Summer. Each year the new Plebe class, about 1,200 strong, arrives at the Naval Academy at the very end of June. For the next two months, i.e., until the upper classes return early in September, the new Plebes are kept busy with drills, physical conditioning, orientation and indoctrination into a military life and routine. Each Plebe learns how to take care of himself and his personal gear, and how to march, to handle weapons, and to handle boats. He is grounded in naval traditions, customs and usages, and in the importance and responsibilities of watchstanding. He is taught the fun-



Official U. S. Navy Photograph

Figure 25. Sectionalized General Electric J-47 Turbo-Jet Engine in Internal Combustion Engine Model Room—Department of Marine Engineering.

Official U. S. Navy Photograph

Figure 26. Pattern Shop Drill in Department of Marine Engineering.

Official U. S. Navy Photograph

Figure 27. Machine Shop in Department of Marine Engineering.

damentals of personal hygiene, and he is tested for physical development.

In addition to the above the Plebes receive an introduction to the study of marine engineering through examination of sectionalized machinery units, through disassembly and assembly of internal combustion engines, and through instruction in shop processes. Altogether each Plebe has 30 hours in the Department of Marine Engineering, of which 18 hours are spent in the shops. He spends two hours each at electric welding and gas welding, and another two hours in the copper-blacksmith shop. He spends 10 hours going through the various processes in the manufacture of a cable stuffing box gland nut. He makes the pattern and core box in the pattern shop (Figure 26); he casts the nut in the foundry, and then he works the casting into its final form on the lathes in the machine shop (Figure 27). Throughout the entire process he has available to him an engineering drawing of the gland nut. so that he attains some insight into drafting nomenclature prior to taking up Engineering Drawing at the beginning of the academic year. One further purpose of this project is to make him aware of the many steps necessary to make such a simple piece of equipment.

Youngster Cruise and First Class Cruise. At the end of Plebe Year and again at the end of Second Class Year the midshipmen embark on a two-months' practice cruise, usually to European waters. Each year approximately 1,800 Naval Academy midshipmen are joined by about 1,200 senior and sophomore midshipmen of 20 NROTC units throughout the country. This past summer (1956) two battleships, two cruisers and sixteen destroyer types made up the cruise which visited Scandinavian, English, and German ports.

The purpose of the cruises is threefold: (1) to provide an understanding of shipboard organization, administration, duties and responsibilities, including those applying to enlisted men, petty officers and junior officers, (2) to supplement the formal academic education in engineering, gunnery, seamanship and navigation, by confirming through experience much that they have learned in the classroom, and (3) to enhance their cultural knowledge through visits to foreign countries.

Each cruise is in three phases, gunnery, navigation-operations, and engineering, and each midshipman is required to keep a cruise journal for each phase. The new Youngsters become acquainted with the duties of enlisted men with emphasis on "learning by doing." The new First Classmen become familiar with the duties, responsibilities and leadership required of junior officers. Within the midshipman detachment, the Youngsters execute the orders of the First Classmen, under the careful guidance of ship's company officers or officers assigned to the ships from the Naval Academy for the cruise.

Second Class Summer. At the end of two full academic years the Second Class midshipmen participate in Naval Aviation Summer. This program is divided into four parts. The first two weeks are spent in amphibious training at Little Creek, Virginia. After that time the class is divided into four groups, and two groups at a time go on a three-weeks' coastal aircraft carrier cruise, in which they observe carrier air operations at sea and are flown off and on the carrier. During the time they are not on the cruise they are either at the Naval Academy or on field trips. While at the Academy they receive flight indoctrination in seaplanes and practical instruction in pre-flight safety, air safety, and elementary air navigation. The field trips include a three day visit to the Naval Air Test Center, Patuxent River, a one-day visit to the Glenn L. Martin Aircraft Factory, and a five-day visit to naval installations in the Philadelphia area, including the Naval Shipyard, Naval Air Material Center, Naval Air Development Center and Damage Control Training Center.

INTEGRATION

General. Early in this article it was mentioned that one of the most significant characteristics of the Naval Academy's curriculum is the integration of the many courses or subjects. It seems quite appropriate to give a *few* examples of this integration, and for this purpose the reader is referred to Figure 3. To begin with, the basic sciences of Mathematics, Chemistry and Physics are studied very early in the four-year curriculum. All the departments in the scientific-engineering and military-professional areas build up their subjects using these basic sciences as foundations. For example, the midshipman needs to know certain aspects of Chemistry to understand parts of Naval Boilers; Calculus, Mechanics and Physics are required backgrounds for Fluid Mechanics and Thermodynamics. Fluid Mechanics and Basic Mechanisms help the student to understand many of the ordnance mechanisms he faces in the Department of Ordnance and Gunnery. The Plebe drawing course will help him to read and understand sketches and drawings found throughout the curriculum. The tie-in between Spherical Trigonometry and Navigation has already been discussed. Finally, the support rendered the Department of Aviation is significant; aerial navigation is taught in the Department of Seamanship and Navigation, aviation gunnery is taught in the Department of Ordnance and Gunnery, and aerodynamics and aviation machinery are taught as part of Fluid Mechanics and Internal Combustion Engines, respectively, in the Department of Marine Engineering.

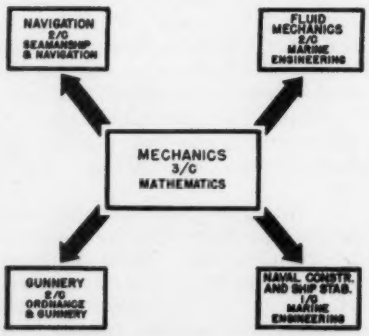


Figure 28. Integration of Mechanics with Other Subjects.

Mechanics. Another way of showing how the curriculum is integrated is to indicate those subjects for which a background in Mechanics is most important (Figure 28). Mechanics, which is taught by the Department of Mathematics during the second term of Youngster or Third Class Year, is conventionally studied under the divisions of *Statics,* which concerns the equilibrium of bodies subjected to forces, and of *Dynamics,* which is the study of the motion of bodies.

The principles developed in Stat-

ics have direct application in the study of Naval Construction and Ship Stability, taken during First Class Year in the Department of Marine Engineering. The basic applicability of Archimedes' principle of buoyancy is immediately apparent. Of equal value and direct applicability are the determination of centers of gravity of planes (centers of flotation), the principle of levers expressed as couples or righting moments, and the determination of moment of inertia in the computation of metacentric radius.

The concepts developed in the study of Dynamics have application in all areas in which analytical knowledge of the motion of a particle, a mass, or a body is essential. In Second Class Year in the Department of Ordnance and Gunnery, the basic equations of kinematics are applied to the trajectory of a projectile; for example, they provide equations for maximum range, time of flight and maximum altitude which are essential to the computation of range tables. In Fluid Mechanics, Second Class Year in the Department of Marine Engineering, the use of vectors in the resolution of forces and velocities, and Newton's law, are essential in analyzing fluid forces; and the principle of conservation of momentum is applied to the analysis of propeller work and efficiency. Finally, the use of vectors in the solution of maneuvering board problems is an obvious example of the direct contribution of Mechanics to the study of Navigation during Second Class Year in the Department of Seamanship and Navigation.

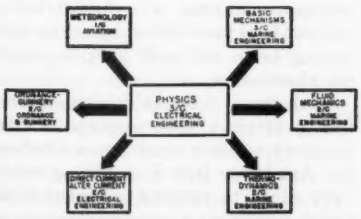

METEOROLOGY I/C AVIATION
BASIC MECHANISMS I/C MARINE ENGINEERING
ORDNANCE GUNNERY I/C ORDNANCE & GUNNERY
PHYSICS I/C ELECTRICAL ENGINEERING
FLUID MECHANICS I/C MARINE ENGINEERING
DIRECT CURRENT ALTER CURRENT I/C ELECTRICAL ENGINEERING
THERMO-DYNAMICS I/C MARINE ENGINEERING

Figure 29. Integration of Physics with Other Subjects.

Physics. Figure 29 shows the tie-in of Physics with other subjects. Physics is taught Youngster Year in the Department of Electrical Engineering, and forms necessary background for *all* engineering and professional subjects taught subsequently; Figure 29, and the following description, depict only a few of the more important examples.

In First Class Year Aviation the concepts of humidity, dew point, wet and dry bulb temperature, and the gas laws basic to adiabatic temperature gradients are expanded and applied to the study of Meteorology. Basic Mechanisms is taught at the end of the first term of Youngster Year in Marine Engineering, by which time the midshipmen have had the necessary phases of Physics. The mechanical principles of levers and pulleys and the determination of mechanical advantage are applied to such devices as bell-cranks, rocker arms, and differential chain hoists. Here, also, the fundamental concepts of acceleration, velocity and rolling contact between bodies are applied to gears, gear trains and cams. In Fluid Mechanics, Second Class Year, the principles of hydrostatistics are applied to problems in manometry and to the determination of forces acting on a submerged body. The principles of hydrodynamics, the concepts of viscosity, and Bernoulli's equation are developed and applied to studies of the flow of incompressible fluids. Physical properties, such as viscosity, density, size and velocity, are combined in Reynold's Number to provide a parameter in the determination of fluid flow characteristics and fluid friction. The fundamental concepts embodied in the gas laws and the theory of specific heats, together with the basic general energy equation are applied to the determination of stagnation pressures of compressible fluids, Mach Number, and general compressible flow characteristics.

Thermodynamics is based almost entirely on principles and concepts originally presented in Physics. The gas laws are developed in terms of a particular polytropic process having immediate application in the engineering field, such as the constant pressure heating or cooling process characteristic of air conditioning systems. In other applications these processes are combined to produce ideal cycles such as the Otto and Diesel combustion engine cycles. The principle of impulse and momentum together with basic vector diagrams and solutions are used in analyzing the energy delivered to steam turbine blading. The principles and basic equations of thermal conductivity are developed in the study of the transfer of heat in condensers and of the effectiveness of insulation for high-temperature steam lines.

In the study of Electrical Engineering, Second Class Year, the applications of the principles developed in the study of Physics are so numerous and so inter-related that isolated individual applications are difficult to determine. Essentially, the study of motional electromotive force establishes the fundamental principle of the electric generator. Ohm's Law and the basic principles of circuits are essential to the development of Kirchoff's Laws for the solution of circuit network problems. Ohm's Law and Joule's Law are applied in the measurement of power and in the heat developed by a current flowing through a resistance. A knowledge of simple harmonic motion is fundamental to alternating current theory. All of these depend upon a basic understanding of the electric field, electric potential, electric charge and electromotive force.

Finally, two examples of the use of Physics in Second Class Year Ordnance and Gunnery are gyroscopic precession and Magnus effect in the study of external ballistics, and the relationship in interior ballistics between the pressure produced by a burning powder charge and the driving force accelerating the projectile.

CURRICULUM REVIEW

The curriculum is kept under rather constant review both internally and externally. Internally, Standing Committee No. 1—the Curriculum Committee — studies recommended changes submitted by individual departments or by the Academic Council (composed of the senior civilian faculty members of those departments having a civilian faculty, plus a senior officer from the professional departments). The Curriculum Committee submits its recommendations for curriculum changes to the Academic Board, who go into the subject and decide what changes, if any, will be made. In the event major changes are involved the Chief of Naval Personnel must give his stamp of approval.

Externally, the curriculum is re-

viewed annually by the Board of Visitors, composed of appointed members of both houses of Congress as well as outstanding individuals from the fields of education and business. Finally, in order to grant a degree to Academy graduates, the Naval Academy must be accredited by the Middle States Association of Colleges and Secondary Schools. This organization inspects the curriculum at least once every ten years, the last time being in February-March 1956.

Each year the Board of Visitors comments most favorably on the steps in use at the Naval Academy for keeping the curriculum abreast of modern developments as they occur instead of allowing the subject matter to remain static. This, of course, applies throughout the scientific-engineering and military-professional areas. For example, the latest innovations in electronics, ordnance, aviation and marine engineering are added to the curriculum as they arise. One example of this, involving a number of departments, is the curriculum coverage of the use of nuclear power in the Navy.

In the Department of Electrical Engineering the time spent in nucleonics in the Plebe Chemistry course has been gradually increased since World War II until now there are 5 lessons in atomic structure and the periodic table, 8 lessons in nucleonics, and a 90-minute movie on atomic physics. In Youngster Physics, 8 lessons plus 4 lectures in nuclear physics and atomistics are given.

In the Department of Marine Engineering the most important phase of nuclear power is nuclear propulsion. In First Class Year, as part of the Internal Combustion Engine course, two lessons are given, and the textbook incorporates this subject. The timing of this course is being shifted to Youngster Year Naval Machinery. Elsewhere in the Marine Engineering Department the coverage of nuclear power is aimed at keeping the midshipman aware of the existence of nuclear power. For example, in Second Class Year several problems in Fluid Mechanics and Thermodynamics are built around a nuclear propulsion plant. In Youngster Year the materials particularly adapted to use in connection with nuclear power are emphasized, and in Plebe Year one or more assembly plates that pertain to some valve or fitting used in a nuclear plant are used in Mechanical Drawing.

The other phase of nuclear power in the Navy, i.e. atomic weapons, is covered by three departments, and is supplemented by a four-hour secret lecture given to First Classmen by a team from the Special Weapons School in Norfolk. The Department of Ordnance and Gunnery gives the First Class four lessons covering basic material in special weapons. The Department of Aviation gives 5 lectures on special weapons to the First Class. Finally, in Hygiene, one of the 8 lectures is devoted to the medical aspects of the atomic bomb.

CURRICULUM IMPLEMENTATION

Marks. Marks are assigned on a numerical system of 0 to 4.0. 4.0 is the highest mark and is equivalent to 100%; 3.40 and above, corresponding to 85-100%, indicates distinctive performance or "starring"; 2.50, equivalent to 62.5%, is the lowest passing mark.

Marks are assigned on the basis of recitations or quizzes in the classroom, and on the basis of examinations given at the end of each term. In computing the final mark for the term, the average of the former, which are known as the "daily" marks, is weighted 3/5, and the term examination mark is weighted 2/5. On the basis of this combined mark each midshipman is assigned a relative standing in each subject each term. An individual's order of merit for the year is his overall class standing, and is determined by considering the weighted mark in each subject, the weighting factor being dependent on the amount of classroom and laboratory time assigned to the subject. Finally, the order of merit for the four-year curriculum, based on the marks for all four years, appropriately weighted, determines the relative position of each graduate on the list of Ensigns, U.S. Navy.

Up until about ten years ago, as many readers will remember, the procedure in use at the Academy was, in effect, to obtain a mark for each midshipman in each class each day. The present system leaves the decision regarding the number of marks to the Head of each Department, the normal procedure being to obtain a *minimum* of one mark each *week*. Hence the so-called "daily" marks are not actually daily marks at all except in a certain few cases. For example, in Engineering Drawing, where the student is actually performing work at each recitation, and in Foreign Languages, where daily oral recitation is desired in teaching conversational language, marks are taken at almost every classroom session—but these are the exception rather than the rule. For the usual course where marks are not obtained each day, the midshipmen do not know ahead of time whether or not they will be marked on a particular day. This tends to ensure that they will study their assigned homework, and such daily preparation encourages progressive understanding of subject matter and develops the habit of day-to-day responsibility.

To reward academic proficiency the age-old custom of permitting the "star" men (those attaining an overall mark for the year of 3.40 and above) to wear stars on the collar of their full-dress uniform still obtains. In addition, a recent innovation has been the establishment of a "Superintendent's List," comparable to the college "Dean's List," with certain tangible benefits accruing to those who make the list. The current standards call for an academic average of 3.30 or above, together with a 3.20 in aptitude, and a satisfactory conduct record.

Attrition. Each midshipman is required to pass all courses each term. There is no provision, similar to the normal collegiate procedure, for permitting a student who has failed a subject to repeat that subject the following term and still keep up with his classmates.

Each term, those midshipmen who fail to attain a final average of 2.50 in every subject must appear before the Academic Board. A failing mark very close to passing, coupled with other favorable considerations such as performance in other subjects or in the Aptitude system, may result in the granting of a re-examination; otherwise the midshipman is discharged. If those granted re-examinations pass those examinations, they are considered to have passed the course; but if they fail, the Board's only recourse is to discharge them, or turn them back into the next lower class. The latter action is

usually taken only in the case of midshipmen who have had excessive hospitalization.

The academic attrition and the total attrition in recent years have been as follows:

Class	Academic Attrition %	Total Attrition %
1952	13.5	24.9
1953	11.8	21.6
1954	15.7	25.4
1955	17.6	32.6
1956	17.2	35.6

The attrition other than for academic deficiencies is composed of physical discharges, aptitude discharges, conduct discharges, and voluntary resignations, with the last representing the largest number and also forming the reason for the rather large variation from year to year. For example, of the Class of 1956, 11.6% resigned, 4.4% were discharged for unsatisfactory conduct, and 2.3% were discharged for physical deficiencies. Each year a large portion of the resignations are accepted during Plebe Summer. These are usually comprised of those individuals who, after a month or two at the Academy, decide they do not want any part of a military life.

As indicated above, the academic attrition is not fixed. It is not the result of any policy to see that a certain number of midshipmen fail. The Naval Academy does not mark "on the curve."

Sectioning. The normal recitation group or "section" is composed of about 14 midshipmen and an instructor. It is obvious that these groups are much smaller than in most, if not all colleges, thus permitting enthusiastic and close contact between instructor and student. Laboratory work may be accomplished on an individual basis or by groups of two to seven midshipmen, depending upon the department or course concerned. In all cases one instructor supervises the laboratory work of a section, and in the vast majority of cases this instructor is the same one who teaches the section in the classroom. In other words, midshipmen are never turned over in large groups to teaching fellows or student assistants, a practice rather common in engineering schools.

At the end of each half-term and term the instructors for each section are shifted. This permits a more equitable treatment for the midshipmen since at the Naval Academy, as elsewhere, instructor capability varies. Since all sections are at the same point in coverage of the assigned work, this shifting of instructors has no effect on the continuity of the courses.

The method of assignment of midshipmen to sections has changed from what it was ten or more years ago. In those days the midshipmen with the highest marks for the previous marking period were in the top section, and so on down to the bottom or "anchor" section, which consisted of those with the lowest marks. Such sections are called "homogeneous" because within each section the midshipmen would possess about the same ability. Nowadays, with the few exceptions noted in the next paragraph, sectioning is usually accomplished on a random basis or on a balanced basis. Random sections are usually used during Plebe Year when there is little or no basis on which to judge the new students. Balanced sections, in which each section is composed of students of all ranges of academic ability, such that the average ability in all sections is nearly equal, are normally used thereafter. For example, the sections in Fluid Mechanics and in Electrical Engineering are balanced on the basis of the Physics marks the previous year; Internal Combustion Engine sections are balanced on the basis of Thermodynamics marks, etc.

In a few cases "savvy" sections are formed, usually on the basis of one in each half-battalion, which is the normal grouping of midshipmen having a class in one subject at the same time. A "savvy" section is one containing the midshipmen possessing the greatest ability in each recitation group. The students in such sections can be given advanced work within the same lesson content, thus having their assigned time more gainfully employed, and stimulating initiative and ambition. When "savvy" sections are used the remaining midshipmen are arranged in balance or random sections. To cite two examples, "savvy" sections are used in Engineering Drawing and Descriptive Geometry, and in the Plebe Composition and Literature course. In the former the sections are formed at the end of the first half of the first term based upon performance in drawing to date and on the results of the spatial phase of the Naval Academy Aptitude Test taken at the time of entrance examinations. The students are assigned more complicated plates and obtain extra shop work. In Composition and Literature the sectioning is accomplished at the beginning of the term, based upon the grades on the entrance examinations, the verbal phase of the Naval Academy Aptitude Test, previous courses (e.g., in college), and the grade in a Plebe Summer examination. These midshipmen take the same course as those in the regular sections, except that they study complete books instead of selections in an anthology.

Daily Routine. The working day is divided into seven 50-minute periods, the first beginning at 7:55 a.m. and the last ending at 3:55 p.m. Each classroom period is 50 minutes in duration and each laboratory period is 1 hour and 50 minutes long. The value of 3-hour laboratory periods, similar to those of many engineering schools, is recognized, but the tight schedule does not permit periods of this length. These laboratory and drill periods are scattered throughout the day rather than always occurring during the 7th period or on Saturday mornings as they were in earlier years.

The number of classroom periods in the 39-hour week varies from 13 to 17, depending upon the curriculum year involved, and the number of laboratory or drill hours per week varies from 13 to 5. For each classroom period there is an equivalent study period during the regular working day, and six evenings each week there is a compulsory 2-hour study period. Accordingly, the ratio of study time to classroom time varies from 1.7 to almost 2.0.

Extra Instruction. In order that no midshipman may be given an advantage over others, individual, private tutoring is strictly forbidden. In other words, the only tutoring allowed is that which is available to all midshipmen that desire it. This tutoring is known as "extra instruction," and it takes place on a regularly scheduled basis after the end of the last period of the afternoon. Each department is regularly scheduled for two 1½-hour periods each week for each class taught by that department, and the schedule is so arranged as to permit those students needing help in more than one subject to obtain it with a minimum of conflict between subjects.

For the three upper classes extra instruction is purely voluntary. The

Plebe, however, whose mark in any subject is unsatisfactory (i.e. below 2.50) for the term to date, must attend extra instruction each scheduled period until he brings his mark up to the satisfactory level. After that time he is welcome to come, but it is voluntary on his part.

In addition to the regular extra instruction, for those midshipmen who are in the hospital and who are able to attend, each department provides hospital instruction in accordance with a published schedule. Midshipmen in the hospital may be assigned marks when attending this instruction if they so desire. Hence hospitalized midshipmen can in many cases keep up with their academic work.

Teaching Methods. Because the entire academic system is a competitive one and because all midshipmen of any one class take the same examination in each subject, the material to be covered in each subject is maintained on an even-front basis. In other words, each instructor must cover the same lesson material in any one day. Lesson assignment sheets are published in advance so that each student knows just what work he is responsible for at each recitation.

In addition, the written quiz for any one recitation is standardized, even though the general procedure is such that the instructor may give the quiz in its entirety, use only selected parts of it, or not use it at all. In all cases, however, each midshipman ends up several days later with a copy for use in studying for the term examinations.

One might come to the conclusion that the instructor is "regimented" in that he must cover the same lesson material in any one day, in that the written quizzes are standardized, and in that he must periodically check the progress of his students by assigning a certain minimum number of marks. Actually, this is where the "regimentation" ends, because the preparation and use of a lesson plan, the method of teaching, the securing of student cooperation, and the promotion of learning are all the responsibility of the individual instructor.

Each instructor is encouraged to use the teaching method or methods most effective for him. This could be the lecture, the recitation (oral or written), the group discussion, the use of questions and answers, or any combination of these. He is also encouraged to develop any visual aids he believes will be effective, and at the Academy many are available to him. In the majority of cases in engineering subjects the instructor delivers an informal lecture on the day's assignment, correlating it to previous lessons and perhaps indicating the direction toward future material. The students are encouraged to participate by asking questions or by answering questions posed by the instructor. During this procedure the emphasis is on the most significant phases of the day's assignment and not on a mere repetition of the assigned text material. Periodically the last 15-20 minutes are used for a written quiz, although, as previously indicated, each instructor is free to decide whether or not to give a quiz, within the rather general requirements regarding the minimum number of required marks. Furthermore, he can occasionally give the quiz at the start of the period before the day's material is discussed.

"Old-timers" will find the above quite different from the old "draw-slips - and - man - the - board" technique, where in many cases the instructor did little or no teaching, but simply served as a referee between the midshipman and the day's assignment. Today there is much more actual teaching being accomplished and the technique of drawing slips and answering them on the blackboard is used so infrequently that to all practical purposes it has vanished from the Academy scene.

Every college has its extracurricular program but the author doubts that many of them compare favorably in quantity and variety with that of the Naval Academy. Figure 30 is a listing of the extracurricular activities, dividing them into eight major groups. All of these activities are organized and operated entirely by the midshipmen, although in each case an officer or civilian faculty member is designated as the faculty advisor or representative.

Only two of these groups will be discussed herein, after a brief explanation of a few of the items in the remaining six that might not be clear to many readers. The Trident Society provides a means for the expression or publication of the talents of midshipmen interested in arts or letters. Under Class Activities the "Lucky Bag" is the yearbook of the graduating class. Under Brigade Activities the "Log" and the "Log

EXTRACURRICULAR ACTIVITIES

INTRAMURAL SPORTS
- FOOTBALL
- SOCCER
- CROSS COUNTRY
- BASKETBALL
- WRESTLING
- BOXING
- SWIMMING
- WATER POLO
- GYMNASTICS
- FENCING
- SQUASH
- PISTOL
- BOWLING
- FIELD BALL
- VOLLEY BALL
- HANDBALL
- TABLE TENNIS
- TOUCH FOOTBALL
- CREW
- TRACK
- LACROSSE
- TENNIS
- GOLF
- SAILING
- SOFTBALL
- STEEPLE CHASE

TRIDENT SOCIETY ACTIVITIES
- TRIDENT SOCIETY
- ART CLUB
- CHRISTMAS CARD COMMITTEE
- HOUSE LIBRARY COM.
- PHOTOGRAPHIC CLUB
- REEF POINTS
- TRIDENT CALENDAR
- TRIDENT MAGAZINE

CLASS ACTIVITIES
- CLASS ORGANIZATIONS
- CLASS CREST & RING COMMITTEE
- LUCKY BAG
- CLASS HOP COM.
- RING DANCE & FAREWELL BALL COM.

RELIGIOUS ACTIVITIES
- N.A. CHRISTIAN ASSN.
- NEWMAN CLUB
- PROT. & CATH. CHOIRS

THEATRICAL & MUSICAL ACTIVITIES
- MASQUERADERS
- MUSICAL CLUBS
- GLEE CLUB
- CONCERT ORCH.
- NA-10
- JUICE GANG
- PROPERTY & MAKE-UP GANG
- STAGE GANG

HOBBY CLUBS
- CHESS CLUB
- MODEL CLUB
- SOUND UNIT & MOVIE GANG
- STAMP CLUB

PROFESSIONAL CLUBS
- BOAT CLUB
- FOREIGN LANG. CLUB
- RADIO CLUB
- ENGINEERING CLUBS
  - PHYSICS BRANCH
  - MECH. BRANCH
  - AUTO. BRANCH
  - ELECT. BRANCH
  - AERO. BRANCH
  - NAV. CONST. BRANCH
- RADIO STATION WRNV
- FOREIGN REL. CLUB
- MATHEMATICS CLUB

BRIGADE ACTIVITIES
- BRIGADE & CLASS EXEC. COM.
- BRIGADE ACTIVITIES COM.
- DRUM & BUGLE CORPS
- BRIGADE HOP COM.
- THE LOG
- THE LOG SPLINTER
- PUBLIC RELATIONS COM.
- RECEPTION COM.
- VARSITY "N" CLUB
- GOAT KEEPERS
- FORENSIC SOCIETY

Figure 30. Extracurricular Activities Program.

Splinter" are bi-weekly student magazines (published on alternate weeks).

Many people are aware of the fact that in intercollegiate athletic competition the Naval Academy with 20 varsity sports has one of the largest programs in the country. But not as many are aware of the large intramural sports program totalling 26 sports. Every year over 90% of the Brigade of Midshipmen participate in this program, there being over 3,000 contests annually. The remaining 10% consist of those midshipmen who engage in several varsity sports and of those unable to participate because of academic difficulties. Most of the latter are Plebes.

It has already been mentioned that the Naval Academy curriculum, being fundamental, does not provide for specialization. However, the Professional Clubs can and do provide a measure of specialization for those interested midshipmen. Like all other extracurricular activities the work of these clubs is performed during the midshipmen's free time—i.e., between 4:00 p.m. and 7:00 p.m., and for a short time after the evening meal. Each year representatives of the Engineering Clubs attend meetings of various technical or professional societies, and in some cases participate in papers competitions held at regional conferences of student branches of various societies. In 1953 and 1954 a midshipman (a different one each year) was awarded first prize in a papers competition of the Northeast Regional Branch of the Institute of Aeronautical Sciences. In 1955 a third midshipman also took first prize in a similar competition of the Southeast Regional Branch of the same society. In 1956 a midshipman took second prize for a paper presented at a meeting of the American Institute of Electrical Engineers. In all these cases the midshipmen concerned were competing against students from our better schools in the East, and the majority of these competitors were specializing in a field of engineering, whereas the midshipmen were not.

THE FACULTY

The Naval Academy faculty is composed of about 200 civilian professors and 290 officer instructors. The latter are mainly Naval officers but all the Armed Services are represented. This figure of 290 consists of officers actually engaged as instructors, i.e., it does not include the officers attached to the Executive Department, nor does it include officers assigned administrative duties in the academic departments.

The officer-civilian proportions vary among departments. In the professional departments — Ordnance and Gunnery, Seamanship and Navigation, and Aviation—the faculty is 100% military. In Mathematics, Foreign Languages, Physical Education, and English, History, and Government three-fourths of the faculty is civilian. In Electrical Engineering one-third is civilian, and in Marine Engineering one-eighth is civilian. Efforts have been made to attain a ratio in the faculty of one-half civilians in Electrical Engineering and one-fourth in Marine Engineering, but at the present time, like most colleges, the Naval Academy cannot compete with private industry for the talent required.

Each element, civilian and military, has a most important place in the Naval Academy's program. The civilian faculty members provide continuity and a greater depth of background and experience in the teaching of many subjects. On the other hand, the officers reporting from Service duties bring with them constant reminders of the goal on which the entire academic effort is focused. Further, in the teaching of professional subjects these officers use not only the textbooks but also the experience gained by them in their service afloat.

The educational attainments of the civilian faculty are high. Over 30% have earned their doctorates, and 92% have either a doctor's or a master's degree. Under rules in force since World War II, a new member of the civilian faculty must bring with him to the Academy at least a master's degree and at least one year of successful college teaching experience. Furthermore, for promotion to full professor he must have a doctor's degree, unless an exception is made in his case. A considerable number of the civilian faculty undertake advanced study during the summer months, and during the evenings the rest of the year at colleges in nearby Washington or Baltimore, or through extension courses now being offered by George Washington University. Some of this advanced study is undertaken for the purpose of attaining appropriate degrees, and some for the simple purpose of enhancing individual teaching ability in specific courses.

Other characteristics of the professional activities of the faculty include widespread participation in educational and professional meetings, participation on a consultant basis or on a loan basis to various governmental activities, and the writing of numerous books and articles. As has been inferred throughout this article a number of textbooks used at the Academy are written by members of the faculty to suit the peculiar needs of the Academy's curriculum. In addition, a number of books, particularly in the fields of naval history and mathematics, have been written by faculty members for purposes other than Naval Academy textbooks.

Whereas the civilian faculty remains rather constant from one year to the next, there is a large turnover each year in the military faculty, brought about by the fact that for the junior officers a normal tour of duty is two years. To obtain the highest possible effectiveness from the new faculty members, an instructor indoctrination program is required. This is in two phases—extra-departmental and departmental.

Every effort is made to have new instructors report for duty at least a month and preferable two months before they will have to start teaching. The extra-departmental program is held early in August each year, and includes lectures in educational psychology, teaching methods and procedures, effective speaking, and Naval Academy orientation. It also includes practice-teaching and effective-speaking sessions under the guidance of experienced faculty members.

In the departmental phase each academic department indoctrinates the new instructors assigned to it. These programs include refresher courses in the particular subject or subjects to be taught, indoctrination in departmental teaching procedures, and an expansion of the practice-

teaching part of the extra-departmental program. While each department handles this in a somewhat different manner, a typical procedure consists of a complete briefing, lesson by lesson, of the subject(s) involved, during the summer months, followed by weekly or semi-weekly seminars during the academic year. During the latter seminars the material causing the midshipmen the most difficulty in past years is explained and important points to be discussed in the classroom are stressed. Each new instructor is encouraged to visit other instructors' classes in order to improve his effectiveness, and his performance is evaluated by classroom visits from his Head of Department, the officer in charge of his particular teaching group, and senior members of the civilian faculty.

CONCLUSION

The Naval Academy curriculum periodically comes under attack from many sources. Some individuals in educational circles, whose specialties are in the arts and letters, criticize what they consider to be too small a percentage of curriculum time devoted to the humanities. Other individuals, of a scientific-engineering bent, consider that there should be a more thorough coverage of engineering or scientific subjects. A third group agues that this or that professional subject should be introduced, or expanded if it is already in the curriculum. It is really not surprising to find naval officer graduates of the Academy in all three groups, and of course they make up the entire third group.

There is no single authority who can tell the Superintendent that the curriculum coverage in any field should be just so much, no more, no less. Accordingly, everyone is entitled to his own opinion. That of the author is that the curriculum is extremely well balanced. While over a period of years the emphasis has shifted to and fro, the changes have been very gradual. Considering the Academy's background of years of experience, that is quite natural and quite proper. There is no doubt that other changes will be considered and, from time to time, effected. In all cases the author is confident that such changes will continue to support the basic education herein described, in proper balance with necessary naval motivation and training.

The flexibility, inventiveness, and unquestioned competence which successful officer-graduates have demonstrated in meeting important and novel situations in both military and business life speak well to the critics for the adequacy of the basic education received at the U.S. Naval Academy.

There are only three colleges or universities in the United States with curricula in naval architecture and marine engineering accredited by the Engineers' Council for Professional Development. These are Massachusetts Institute of Technology, University of Michigan, and Webb Institute of Naval Architecture. In addition, the University of California has marine engineering options as part of an accredited mechanical engineering curriculum.

"JOURNAL OF THE FRANKLIN INSTITUTE"

THE SCIENTIFIC VALUE OF ARTIFICIAL SATELLITES

ACKNOWLEDGEMENT

This is a lecture delivered at The Franklin Institute by Dr. Fred L. Whipple, Director, Smithsonian Astrophysical Observatory, Cambridge, Mass. It summarized the proceedings of a symposium on "Earth Satellites as Research Vehicles," and was published in the August 1956 edition of the "Journal of The Franklin Institute."

THE SUBJECT of tonight's lecture represents to me an unparalleled situation in which there are more activity and more interest in anticipation of a scientific event than in the past history of science. I hope this is a good omen. Sometimes these events don't turn out so well, but in this case I think we are on good sound ground and we are truly going to see an artificial satellite moving about the earth before too long. I would not say exactly when, but within a year or two.

This is rather a remarkable time in the history of the world. One is impressed by the mushrooming of science, the accumulation of knowledge and its use for practical and sometimes impractical things. Today, coming down on the plane, I thought about the various rates at which progress seems to take place. It must now be something like a billion years or so from the time we started out with simple molecules which developed into heavy proteins and small celled animals; then perhaps four hundred million years or so ago, sizable animal life appeared on the planet; and finally, a hundred million years carries us from the time of the early mammals to the place we are today. If you draw this curve, which seems to me very much like the curve of scientific progress during the last century or two, it is what we call an exponential curve. It keeps on getting steeper and steeper as it goes on. The scientific progress on this sort of scale will, I think, in the course of another 50 years or so, probably be as high above the surface of the earth as the satellite we want to talk about.

Now where do we stand in regard to producing artificial moons which revolve about the earth—the artificial satellites? The subject of today's discussion has been what we might do with them scientifically; first, however, I'll take just a little time to discuss their present status and a bit of their history.

I may say that to the best of my knowledge, "flying saucers" do not represent a manifestation in this direction. All the evidence that I can find points against their being inexplicable. In other words, we have as yet no artificial satellites or space travel, although there are some who would like to interpret "flying saucers" as such.

The present satellite program, as you know, was announced by the President of the United States last July as part of our International Geophysical Year Program. The IGY, of course, is not a year or a measure of time, but a united program among the geophysicists of the world to make observations of the upper atmosphere, solar activity, the oceans and the other phenomena that are important in the study of the earth. The program was initiated by various international societies and in this country is sponsored by the National Academy of Sciences. The finances for it are provided by Congress through the National Science Foundation. In the IGY Panel on Rocketry, of which I have the honor to be Chairman, we developed a sub-panel with the code name, LPR. LPR, to us, stood for Long Playing Rockets—rockets that would go around the earth in a satellite orbit and therefore stay up longer than others. The LPR committee looked into the satellite potentialities, practical and scientific. We sent a favorable report to the IGY U. S. National Committee and at that point it rose out of my sight to the higher spheres in Washington, out of telescope range. You know where

it eventually landed; the President announced our Satellite Program last July.

That program, as it has been set up, is controlled scientifically by the IGY committee of the National Academy of Sciences, and financially by the National Science Foundation. Our first step was to collect evidence to the effect that it was perfectly possible by means of modern rocketry techniques to put a small object into an orbit about the earth so that it would become an artificial moon. This is possible in terms of technology today, without new scientific breakthroughs and new types of knowledge, but merely through development of what we now know.

It became immediately evident that only the military is now in a position to put such an object into an orbit and so the President assigned to the Department of Defense the task of doing two things: (1) putting a satellite into an orbit, and, very important, (2) proving that they had done so. That assignment in the Department of Defense was then given to the Naval Research Laboratory as Project Vanguard, which is headed by Dr. John Hagen, an Astronomer at the Naval Research Laboratory. The Glenn L. Martin Company is the primary contractor for the rocketry, but the scientific aspects of this program are in the hands of a group called the "Technical Panel for the Earth Satellite Program" headed by Dr. Richard Porter of the General Electric Company. I have the honor to be a member of that committee along with six or seven others. That panel has the responsibility of deciding what scientific research can and should be done by means of the first artificial earth satellites.

I'd like to spend a little time describing this program and what is expected, because many of you may have read the newspaper accounts. It's a little difficult to determine from them what the exact situation is and how much to read between the lines. The intention of Project Vanguard is to put up into a satellite orbit an object weighing 21½ pounds, probably spherical (at the request of the scientific panel), with a diameter of about 20 inches. It should also be a good reflector, for a mirror-like surface is desirable on the satellite so that it can be observed optically. As to launching, this will probably be done with three-stage rockets. The first stage, which drops off, will be very large, comprising most of the mass and weighing something like 20,000 pounds. It will go up to an altitude of about 40 miles, with a velocity of about 4000 miles per hour, and then fall off. The second stage will continue on upward to about 130 miles; the last stage will carry the small 21-lb. satellite into an orbit with a velocity of about 18,000 miles per hour. It will revolve about the earth in some 100 minutes. The plan is to put it into an orbit so that its minimum distance from the earth is 200 miles and the maximum distance is 800 miles.

Launching will take place from the Patrick Air Force Base at Point Canaveral, Florida. A little geometry will show how this fact affects the inclination of the satellite's orbit to the earth's equator and what regions of the earth it will pass over. Newton showed that a body moving around a spherical earth would move in a plane through its center. Consequently the satellite must start out in an orbit whose plane passes through the center of the earth and also through Patrick Air Force Base. If you can visualize these two planes—one the equator of the earth and the other plane going through a point at latitude 28° N—you will immediately see that they must be inclined *at least* by the angle of 28°, meaning that the satellite must perforce travel in an orbit that is inclined 28° or more to the earth's equator. Thus as it goes around the earth it will pass over all latitudes between 28° N and 28° S. An attempt will be made to place it in a somewhat more inclined orbit, say about 40°, because then it would pass very nearly over Philadelphia! My guess, however, is 35°, which will still make the object somewhat southerly from Philadelphia when it's in the northern-most part of its orbit. The satellite starts out in a direction parallel to the northern edge of the Bahamas, which which stretch out toward the SE from a point in Florida.

There are some problems that limit the directions. People say, "Why not fire the Satellite in an orbit that goes up over the poles?" This would require a northerly (or southerly) original motion toward the poles from the launching site. However, the first and second stages of the rockets are going to go hundreds of miles and land in some spot not completely controlled from the launching site. It might be in the Carolinas or somewhere in Virginia, if we fired north from Patrick Air Force Base. But I'm afraid the people there would not appreciate having such objects falling down at random on their land. And the people in the Bahamas wouldn't like it either. It's a little easier to get people out of the way when they are in ships on the water than it is when they are ensconced on land masses, so it's much better to fire out over the water. Therefore, a polar orbit from Patrick Air Force Base is highly unlikely. You can't fire south, either, without getting into trouble; so it doesn't look as though there would be a very high inclination for these first satellites.

A satellite itself moves around the earth in about an hour and forty minutes, during which time the earth turns on its axis about 25°. This means, then, that the earth is continuously spinning underneath this orbital path which a satellite follows, and so with every successive revolution of the satellite it passes over a region of the earth westerly from the one before, by a longitude difference of something like an hour and a half. As you know, it's about three hours in longitude across the country, three hours of time change, so two revolutions are more than enough to carry the orbital path westerly across the United States, as seen from the ground. The motion of a satellite is extremely rapid. If it is fired from Patrick Air Force Base toward the southeast, it will be over

Africa in about 20 minutes. It's incredible how quickly an object moving 5 miles a second can get around.

Now I'll talk about the nature of the satellite. The Department of Defense has the problem of putting up a satellite and their intention is to be as absolutely sure of accomplishing this as they can. They plan to make six "earnest tries." Six times they will make earnest efforts to put a 21½-lb. satellite, or its brother, up into an orbit. We hope they will be successful with perhaps half of those tries. The first time the chances undoubtedly are the lowest—"bugs" of some sort or another tend to creep in and cause trouble. The second time the assurance will be higher and, as time goes on and more tries are made, we hope that as many as half of them will be successful. Then the IGY hopes to send up six more, making a dozen attempts all together; possibly no two of the satellites will be alike.

As I said, the Defense Department has to prove that they have put one up. How are they going to do this? A 20-in. sphere hundreds of miles away is hard to see. They will put in each satellite a small transmitter operated by batteries, probably not solar batteries in the first ones, nor ordinary batteries, but super batteries lasting as long as possible. This small transmitter will probably operate on 108 megacycles per second (about 3 meters wave length) which will transmit at a phenomenally low power, measured in milliwatts. A very weak lamp uses 10 watts of current. Although the radio source is weak in the satellite, because they can't use very much energy from this finite battery source, the strength of the system lies in plans for very large antennas on the ground, which will capture minute signals. I've forgotten how many acres these antennas will cover, but they will be able to pick up the weak signal from the satellite every time the satellite comes within perhaps 600 miles, and not only determine that it came over, but measure where it was to an accuracy of the order of a minute or two of arc. That's the general precision with which they hope to observe the satellite by radio techniques. Furthermore, the same transmitter will, when requested from the ground, transmit information from a few measuring devices in the satellite. I'll go into that a little bit later.

Now, as you know, there are times when electronics fails. One trouble with satellites is that they're very hard to service. If something happens up there in the transmitter, there is not very much that can be done about it. This is where the Smithsonian Astrophysical Observatory comes into this picture. We have proposed to set up ground observing stations so that we can detect a satellite by its reflected sunlight. This has to be done with considerable care and at the right moment, because on the bright daylight side of the earth a satellite reflects sunlight but you can't see it and on the dark side the satellite will also be in the dark. The only time you can hope to see a satellite will be at the twilight period when the satellite is more or less overhead and the sun has already set a bit below the horizon so that the sky is not too bright. The observer, then, is in the shadow, the sky is rather dark, the satellite is up above in the sunshine. At that time a 20-in. sphere at a minimum distance of 200 miles will be just a hair brighter than the 6th magnitude which, as I'm sure most of you know, is the theoretical limit of the naked eye. What does that mean? It means that if you go out into beautifully clear country air with absolutely clear sky, no moon, no twilight, and you have extraordinarily good eyes—I'm sure I've never seen a 6th magnitude star—you will see the satellite with the naked eye, if you know where to look and when. When close, 200 miles up, it will move a little over a degree per second; that means across the moon's diameter in half a second. However, it doesn't take much optical aid—binoculars, for example—to make a 6th magnitude object really quite conspicuous.

Thus, a satellite should be readily observable if you know where and when to look through binoculars. We hope to do it. We intend to set up two observing programs. I mention the visual one first because it's rather important. Suppose the radio transmitter in the satellite doesn't operate properly in the early stages. It's going to be touch and go to find out just what is happening to the satellite. Here it is sent off in an orbit. But the rocketry is not controlled in the last stage; it's sent off just like a 4th of July skyrocket, precisely built, however—but it needn't go exactly in the direction one wishes. We hope the satellite launching will stay within about a degree or so of its proper course. Then, by the time it goes around once it can still be 60 miles or so away from the direction one expects to see it. So that the first few times around—if the transmitter is not functioning—there may be considerable question as to what happened to the satellite.

For that reason, the Astrophysical Observatory of the Smithsonian Institution has been assigned the task of organizing the optical programs. One important aspect of this task is the organization of the non-professional astronomers and other interested observers into groups so they can systematically look for the satellite and help us find out what happened to it in case the radio tracking did not function.

There is another time when amateur observations will be of extreme importance; that is when the satellite is about to come down. Although it goes up into the atmosphere above the earth where the air density is very low—considerably lower than in the vacuum of a thermos bottle—nevertheless, there's enough air up there to bring it down after a while. You've read various accounts in the newspapers of how long such a satellite will stay up and you've probably seen that these numbers didn't agree very well. There's a good reason for that because nobody knows. Even given an exact orbit, say 200 miles perigee minimum height, 800 miles maximum height, I don't think anybody on the planet can estimate the length of time it will stay up within an accuracy better than a factor

of 3—and possibly not within a factor of 10 either way. We simply do not know the amount of air that exists at altitudes of 200 miles and above, to this degree of accuracy. My own estimate, and I don't have any reason to think it's going to be better than any others, is that the satellite will start falling rapidly in about a year. Now if that's 10 times too high, the satellite will start coming down in six weeks or so. If the air is 10 times less dense, then our best guess is that it may stay as long as 10 years.

So there is great uncertainty here. These astrophysical orders of magnitude sound fairly definite until you try to put them into time or dollars—then the uncertainty begins to show up. Uncertainties of only a factor of 2 become pretty important in dollars. In any case, as the satellite falls down into the atmosphere, the rate at which it comes down, or in other words, the resistance of the atmosphere, is a direct measure of how much air there is up there. Simply by looking at an object—in this case, a sphere with nothing in it at all except its mass,—just moving around in an orbit, one can determine the density of air at various heights up to approximately 300 miles. Rockets give us such data and results have been very surprising up to an altitude of a little more than 100 miles. We know that, at that altitude, the air density has fallen off by something like 1000 million from the sea level value. So the first result, the measure of the air density (air pressure), comes from simply watching the satellite. If we knew the composition of the air we could also tell the temperature. Both are extremely important data about the very high atmosphere.

I was leading to the point that in the last phases of this fall-in, the satellite is going to be changing its orbit very rapidly. First the computing machines will work on this problem, taking all the observations that have been made. The optical observations by the non-professionals, the radio observations that exist, the photographic observations, and any others that are made, will all be fed into one of these large mechanical brains which will predict where the satellite is going to be. This works out very well until the very last stages when the changes in the orbit are so fast that I don't think we can keep up with it Here again the non-professional visual observer with his binoculars is of extreme value in the scientific aspects of the satellite program. As I said, the Astrophysical Observatory of the Smithsonian Institution has been assigned the task of initiating an optical observing program. Dr. J. Allen Hynek of Ohio State University has joined me in this project, heading it as Associate Director. For the non-professional astronomers, we have asked Dr. Armand Spitz, whom many of you know, to head the organization. If any of you would like to get into this program go to him or to your local astronomical organization—and volunteer to work with that group. Extremely valuable observations can be made by groups working in that fashion.

The problem of predicting where the satellite will be requires quite a performance from the computing machines. It takes considerable calculations just to predict where it will be at a given instant, such as at 12 o'clock noon, Greenwich civil time, on a given day. For ordinary astronomical predictions we calculate where a comet is going to be once every five days, which is usually quite adequate; a very fast moving comet requires a prediction every day. In the case of the satellite, predictions are required about once every minute, or 1440 times per day—and even then this is not a fine prediction series because in a minute the satellite moves 300 miles. We can locate points on the earth's surface 300 miles apart at minute intervals. Those computing machines had jolly well better compute an ephemeris position in less time than one minute, or we can't keep up with it.

I won't go on in that vein any more except to say that the motion of a satellite is quite complicated. The trouble is not that the sun attracts it, for the sun's attraction is practically the same for the satellite as it is for the earth; the same holds for the moon. The trouble is that the earth is not a nice sphere with all the mass symmetrically placed about the center. Newton long since showed that if you had a sphere perfectly symmetrical about the center, the attraction would act as though the entire mass were concentrated at the central point. But the earth is in rotation so that it has an equatorial bulge; it's 13 miles greater in radius at the equator than it is at the poles. As a consequence, the earth has an extra "spare tire" attached around its equatorial belt—the sort of thing that happens to some of us as we pass into middle years! This extra mass around the equator attracts the satellite a little more strongly than it would, had all that mass been distributed spherically. This means that the orbital path, instead of remaining in a plane with the elongation of the ellipse in the same direction, keeps swinging around toward the west. It takes something like 40 or 50 days in the earlier stages, somewhat less time later on, for the pole or the plane to swing around in a westerly direction in this fashion. That's one complication. At the same time the long axis of the orbit will swing around in a forward sense as the satellite moves about the earth. Thus the nearest point to the surface of the earth moves in the plane around in the eastwardly or positive direction.

Then there are certain complicated little motions that take place so that the path at no time is a nice ellipse. Astronomers always talk about ellipses for the motions of heavenly bodies but there are no ellipses; they're always impossibly complex figures as is true in this case. One can handle the motion by complicated theoretical methods, a long series of expansions or by the computing machines. One of the little problems that worries us at the present time is the effect of what are known as gravitational anomalies on the earth. This may be a new term to some of you but the earth isn't even a perfect flattened-out spheroid. In some places there is a little more mass which attracts bodies like the satellite more, and at-

tracts you too. I mean that if you're in a positive gravity anomaly you weigh a little more than if you were a few miles away where there is a negative anomaly. We haven't quite figured out yet what these effects are going to do to a satellite's motion. They may produce irregularities in the motion, which could make it hard for us to predict the motion as accurately as we would like.

Now a bit about the scientific results we expect from the satellite. The equipment inside each satellite will measure some physical quantity, probably two or three. In the earlier ones there may be devices that will measure, for example, the noise when a meteor pings the surface of the satellite. These little dust-like particles are not big enough to make visual shooting stars before they get into the earth's atmosphere (they are moving along anywhere from 7 miles a second up to 45 miles a second), but, upon striking the surface of the satellite, they will make a noise which can be picked up by a very sensitive microphone. Some of this work was done by Dr. Lloyd Bohn at Temple University here a number of years ago with rockets and I hope that he is going to have a device in one of the early satellites to measure the number of these dust-type meteors that strike into the earth's upper atmosphere.

We would like to know how often a sphere like this will be punctured by meteors. I became interested in this just after the war in 1946 and made some calculations. I've been revising them ever since and I'm still not sure of the answer. The best way to get the answer is to put a little bit of air pressure in the satellite, then add a pressure measuring device, which will then give you a record of the pressure in the sealed up sphere. If a little hole is punctured by a meteorite, the pressure will fall off and by measuring the rate of fall you can determine the size of the hole made.

Then there will be devices for measuring the temperature, to see what the solar radiation does. You can also measure other physical characteristics of the satellite itself. That type of apparatus will almost certainly go in the first one and the measurements by this equipment will be sent to the ground by coded radio signals which will be picked up by the large antennas. Such a system is called a telemeter system. It has been used with great success in the sounding rockets in New Mexico and in other such investigations. Ten years ago it was a novel device. The Navy was instrumental in building early ones. Today it is an extremely reliable system whereby you could read a hundred instruments in a large rocket to an accuracy of one per cent, perhaps a hundred times a second, and collect all the information on the ground by radio. In the satellite system there will be only a few measuring devices and they won't be read so often as that because there won't be enough power. But a number can be read.

One observation which will certainly be made in one of the earliest satellites will be a measurement of cosmic rays. Down here, the atmosphere blocks off most of the cosmic rays but the cosmic rays in coming through cause secondaries; they hit atoms and break off more pieces that go on to strike us at high velocities. Cosmic rays are mostly hydrogen nuclei, moving with a velocity nearly that of light, but it is hard to distinguish the original ones that come from space from the secondaries they make in the atmosphere. This, incidentally, is one of the interesting points about the danger of cosmic rays in space. You would think that if you're out in space where you would be exposed to the primary cosmic rays, you had better put something between you and the cosmic rays. The effect of this would be very much like putting a window pane between you and a bullet. The bullet might not hit you if you didn't have the window pane there, but the shattered glass fragments might be more serious and damaging than the bullet itself. Such is the effect of having a small amount of shielding from cosmic rays in space. You're worse off than if you didn't have any at all.

One of the major questions is not yet clearly resolved—whether some of the weaker cosmic rays come from the sun or whether their variations with solar activity are caused by changes in the earth's or the sun's magnetic field; thus variable magnetism could act as a valve, which controls the number that come down where we can measure them. If we can get direct cosmic ray measures out in the satellite orbit, well above the dense part of the earth's atmosphere, then we can learn a lot about the origin of the cosmic rays and perhaps settle this particular problem. At the same time we can measure the particles that are coming out from the sun. In recent years it has been demonstrated that the sun is shooting off hydrogen atoms,—not merely the nuclei as the electrons have to come along too, shooting off these hydrogen atoms up to 2000 miles a second and continuously. We used to think that space was completely clean, practically free of matter altogether. Now we believe that there are perhaps two hundred of these atoms at one time in any cubic centimeter well beyond the earth's atmosphere. More shoot off when the sun becomes active (related to sunspot activities and so forth) to produce the Aurora Borealis when they strike the upper atmosphere.

And of course we are extremely interested in the solar activity in the far ultraviolet, in fact over all regions of the spectrum. Visual radiation comes in wave lengths of light about one 50-thousandth of an inch long. We can see through just a little crack in what is called the electro-magnetic spectrum, which starts 'way out in the gamma ray region, through the X-rays, the far ultraviolet, the near ultraviolet, the violet, the blue, green, yellow, red, deep red and finally infrared waves, before we come to the radio range. We can look through just a little crack or window in this entire range of energy, which is pouring on us from the sun and from the stars. The reason that this little window is so narrow is because of absorption by the earth's atmosphere. This atmosphere is very good for astronomers but very bad for astron-

omy. It is the greatest bane to astronomy that I know of. If we can get above the atmosphere, all this radiation comes pouring into our measuring instruments. The most interesting things happen to the sun out in the far ultraviolet where we can make no measures whatsoever from the earth's surface; from rockets, we can make measures of perhaps a minute's duration, but the satellite will stay in the sunlight 45 to 50 minutes at a time. We can then find out how the sun varies when it changes its light in the far ultraviolet and how it produces magnetic storms and the Aurora Borealis that I mentioned. The sun can produce trouble in power lines; it affects the ionosphere that reflects radio waves so that it can completely foul up radio communication. We want to find out what is really going on in the sun.

Now the small satellite will probably not carry more than two or three of these experiments at a time, because most of the mass has to go into the radio equipment, the batteries, and the framework of the satellite. If you want to put an experiment into one of these, you are perfectly welcome to compete with the others—it will be a very real competition. All you have to do to your measuring equipment (esentially physical laboratory equipment) is to reduce the weight of everything—the equipment itself, plus batteries and all the connections—from a ton to 13 ounces, and you might win. That's the type of competition that's going on now and anybody who knows his way around in transistors and miniaturized radio sets has an advantage over the others in getting his equipment into this earth satellite. Just let Dr. James van Allen of Iowa State know of your desire and ability to work in this field. Other experiments will be done probably two at a time, such as the measurement of magnetic fields around the earth, other measurements of light, the composition of earth's atmosphere, and the amount of light scattered near the sun.

If we can ever get a camera up there to photograph the stars in the far ultraviolet, we are going to find that the sky looks altogether different from the way it looks now, photographically or to the naked eye. Mr. Robert J. Davis, a graduate student at Harvard, has calculated what the constellations would look like in the far ultraviolet, and he found that almost all of the bright UV stars are in the Milky Way, so the Milky Way will be very much more conspicuous than it is to the naked eye. The constellation Orion will be just a mass of stars. There will be a lot more in the belt; the only old friend you will miss is Betelgeuse. Betelgeuse is too red to have much light in the ultraviolet, so Orion will be cut off at his feet. On the other hand, the Big Dipper will be reduced to two conspicuous stars, so it can't hold water any more. It will be a very interesting day when you can see actual photographs made in this far ultraviolet X-ray region, reaches of the spectrum that never have been seen or photographed by men.

With reference to this satellite, I'd like to mention some of the results that we can hope to get by optical means and to discuss the program that we are initiating at the Astrophysical Observatory of the Smithsonian Institution. We hope to set up about 12 stations over the world utilizing large Schmidt cameras with about 20-in. aperture and about 20-in. focal length with a 30-in. mirror. In the stations we hope to measure the time accurately to about a 1000th of a second, keeping a crystal clock tuned to WWV and then measuring the instants of the photographs. I won't go into details of that except to say that we believe we can measure across the direction of the path to an accuracy of about 2 seconds of arc. That would be about 1000th of the sun's or the moon's diameter. Along the direction of motion the accuracy should be of the order of 5 seconds of arc.

The significance of this becomes apparent. Suppose at a given moment that we know, from all the observations, the orbital path of the satellite to a high degree of accuracy. Then when we know the direction to a point in the satellite's orbit at a precisely determined time, we can determine our position on the earth to an accuracy of a few feet. In practice we will keep improving our knowledge of both a satellite's orbit and the positions of the observing stations. We hope indeed by this method to be able to determine the relative positions of about 12 to 15 stations over the earth, with respect to each other and with respect to the center of the earth, to an accuracy of something like 30 feet out of the 4000 miles to the center of the earth. That is about 10 times as accurate as measurements by geodetic surveys and we hope then to be able to tie in the surveys made in the United States with those made in other parts of the world. Astronomically we can't yet tie those together with an accuracy even as high, perhaps, as 300 feet. Some islands are off by as much as 2000 feet or more by astronomical measures. And then we can determine the shape of the earth. We can determine the size of the equatorial bulge and find out whether the earth is longer in one direction around the equator than it is in another direction, to see whether there is a third axis of the earth. Then we can determine quantities concerning the gravity, the density of material, and isostasy, the plastic flow represented by the way continents spring back up after being depressed by ice in the Ice Ages. You perhaps know that Finland is still rising. That's the type of result that we hope to get from these precise observations.

I've been asked to report on the day's proceedings. Homer E. Newell of the Naval Research Laboratory opened the morning session with a talk about Project Vanguard and the International Geophysical Year. That's a long story involving some 43 nations. The huge program includes antarctic studies, oceanographic studies, studies of the aurora and so forth, and the satellite program is blended into that, as I mentioned earlier.

Then Krafft A. Ehricke, of Convair, discussed aeronautical and space medical research with automatic satellites. That's looking forward to the day

when men ride out into space. There are extremely important problems of the satellite situation that already exist in our aircraft; men now go far higher than they are able to exist unless they take an environment along with them—that is, atmosphere, pressure, moisture, and so forth. Studies of that sort can then very possibly be made by the satellite program, for future satellite programs.

Next George H. Clement of the Rand Corporation discussed a possible Moon Rocket, and some of the problems, including how you shoot a body out there and how you make it either land on the moon or go around the moon so you can photograph the other side. One of the very interesting problems of the moon is whether it has any atmosphere at all. Out in space, we could determine whether there is a little bit of residual atmosphere—maybe some heavy gas like krypton or xenon. We know now that there is less than about 10^{-12}, which is one over a million millions as much air on the moon as there is above the earth's surface. So the moon rocket looks like a development that will follow very shortly after the first satellites. One of the interesting results will be to settle the question of whether maria, or so-called seas of the moon, are old lava flows and hard, or whether (as Thomas Gold in England suggests) they may be just big bowls filled with dust. He warns all travelers to the moon not to set their rockets down in the middle of one of the maria because they may settle into a mile deep ocean of dust. This would be very undesirable! We should know about this question before we send any manned vehicles up there.

In the afternoon program, the first lecture was by Lyman Spitzer, Jr., of the Princeton Observatory, who was discussing astrophysical research with an artificial satellite. He stressed particularly the problem that I mentioned, of measuring the earth's density and pressure in the high atmosphere, how much air is there, and then went into the problem of putting telescopes into satellites. This is a bit farther into the future, because the present 21½-lb. sphere, with a 1-lb. allowance for an experiment, will not allow much of a telescope. But later on we expect to have telescopes there that can be directed. We already have them on the rockets and that's a much more difficult task because you have so little time to get the telescope pointed towards the sun. With the satellite, then, we shall be able to measure the individual stars in the far ultraviolet; a great many results of scientific interest will come out of this.

Just to give you an example, we're very much interested in the radiation of the night sky. When you look at the night sky, you see that there's a certain amount of light. I'm not talking about the artificial light you get over a city. At this stage of the game, with very simple equipment, one can hope to distinguish among four different sources of night sky light: light from the upper atmosphere, light from the solar system, light from the Milky Way and light from the distant galaxies. It may also be possible with rather simple equipment, to separate these sources in the far ultraviolet and in the near ultraviolet. Even in the visual region we could possibly determine some answers about cosmology. Are we living in a universe in which everything is blowing up and all the galaxies moving away? Are galaxies short-lived or, as some of the British suggest, would the system always look the same whether we see it now or ten billion years in the past, or ten billion years in the future? We may be able to discriminate among some of those theories simply by measuring the amount of light in the background of the skyline, down to 5 or 10 per cent level of the night sky brightness, the part that comes from the very distant galaxies at incredible distances into space.

Next we heard a discussion by John de Nike of The Glenn L. Martin Company on the effect of the earth's oblateness and atmosphere on the satellite orbit. I think I can summarize his results very quickly: they are complex!

Then Lovell Lawrence of Chrysler Corporation discussed what he called the ASTRO System, the Artificial Satellite Time and Radio Orbit System. He needs *three* artificial satellites. If you had a ship at sea in cloudy weather, by means of a radio antenna and a complicated system you would be able to determine your position at sea, when one of three satellites came over. Even though impracticable yet, this indicates, I think, some of the potential future uses of satellites.

Then Richard W. Porter, who is the head of the Technical Panel for the Earth Satellite Program, discussed the very difficult and also very important problem of whether it is possible to recover physical information from a satellite after it falls through the atmosphere. In rocketry this turned out to be fairly simple. One of the first ones sent up—a V-2 rocket—had a camera in it in a very strong cassette. Pictures were taken from the top of the trajectory and then the rocket came down again. It was going so fast when it struck the surface of the earth that it made a hole about 35 ft. deep and 35 ft. across. Out of several tons of material they recovered perhaps 200 pounds, not including the cassette. The solution of this problem was surprisingly simple. The difficulty was that this rocket was streamlined. It's a good idea to have a rocket streamlined when it's going up, but if it is to come down slowly, it should not be streamlined. The simplest way to solve this is to blow it in two in the middle. This was done during descent and the pieces came down aerodynamically "dirty," as Dr. Porter calls it. As a consequence they landed at moderately reasonable speeds so that the film could be recovered. The problem is a little more complicated with the satellite because it has to be kept from burning up on the way down.

Just a word or two about the future beyond this very first step that's being made. The satellites can be divided into classes by weight, starting off by say a tenth of this one that is planned—a 2-lb. satellite, which is quite worthless. I can't see any merit in sending one up because you can never prove that it

has been done and it has no scientific value. When the order of about 10 or 20 pounds is reached, a satellite object can be built which can, at least, be observed and instrumented to some extent. The next step, using more powerful rockets and with mastery of the technique, is to send up something about 10 times as heavy, say 200 pounds. At this stage, perhaps nuclear power supplies can be utilized, so that the power system will last for years, even decades or centuries. Or perhaps solar batteries can be used to transform solar radiation into electrical energy. Probably a transistorized television system can be included to take photographs from such a satellite.

The next step is perhaps the 2000-lb. satellite, in which all of these things can be done better through the inclusion of a small physical laboratory. At about this size we come, not to the manned rocket, but what I like to think of as the puppet-type rocket. A puppet, remotely controlled from the earth by radio techniques, can do any of the useful things up there that man can do. You see, the senses are useless in space, except for sight and touch and, as a consequence, the puppet needs only television eyes and a feedback servomechanism. Then you can, in effect, be in the rocket by remote control, controlling a puppet, not by strength but by radio, to do about anything a man can do. This appeals to me because it has not been demonstrated how man is going to react to zero gravity fields, which will prevail in space. The puppet would probably be happier working in a vacuum, so there would be no need to carry any air up there. I think he would be more effective than a man. He could be shut off for a year or two and then put to work again later on if there were some need for it.

I do want to mention a type of scientific result that I think would be extremely valuable to all of us when even the 200-lb. satellite perhaps becomes possible—research on meteorology and weather conditions. I think this progress will complete the revolution of meteorology, which is now under way in the form of mechanizing the collection of data and the calculations of weather forecasts. We have almost reached the point where a machine can do better than a man in forecasting weather. I won't elaborate, but merely note that three-fourths of the earth's surface is covered with water; almost nothing is known about the cloud cover over the oceans, and only a very small amount over the land. A relatively simple satellite—by television camera—can photograph the earth continuously, covering the entire surface more frequently than once a day.

I think the greatest scientific discoveries resulting from the satellites will be those we haven't anticipated. Science has always surprised us this way.

To me the satellite represents the most marvelous scientific development that has happened during my life.

As part of the National Hurricane Research Project established under the sponsorship of the U. S. Weather Bureau, a project was planned by the Office of Naval Research and the Naval Research Laboratory to photograph hurricanes with rockets. The rockets were to be equipped with cameras in the nose cones and with air and seaborne location and recovery devices.

C. O. SMITH

MATERIALS PROBLEMS IN NUCLEAR REACTORS

THE AUTHOR

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Note: This paper is based on a presentation which was made by the author at the Eighth Annual Nuclear Sciences Seminar, sponsored by the Office of Naval Research, Oak Ridge, Tennessee, November 25 to December 8, 1956.

INTRODUCTION

THE INTEREST of the Armed Forces in nuclear power plants hardly needs to be indicated. It is common knowledge that the Navy has a nuclear powered submarine, *Nautilus*, in operation, with the *Sea Wolf* expected to soon be in commission, and a number of other submarines building. In addition, studies are going forward for nuclear power plants in other combat type ships up to and including aircraft carriers. The Army Packaged Power Reactor and its possible uses have been well publicized. Both the Navy and the Air Force are vitally interested in nuclear propulsion of aircraft although this has received less publicity.

In building a nuclear reactor, whether for the Armed Forces or for any other agency, a decision must be reached at some point as to what materials can, and will, be used in construction. In principle, the problems in materials in the field of nuclear engineering are no different than in any other field. In practice, the problems may be more difficult due to more stringent specifications, due to the desire to accomplish ends previously considered improbable or impossible, due to the complicating effect of radiation and nuclear requirements, and due to the use of relatively new and "exotic" metals and materials about which little may be known and which may require considerably different handling and processing than the more common materials. The crux of the whole materials problem has been nicely stated by Dr. Norman Hilberry, Acting Director of the Argonne National Laboratory, who has said, "We physicists can dream up and work out all the details of power reactors based on dozens of combinations of the essentials, but it's only a paper reactor until the metallurgist tells us whether it can be built and from what. Then only can we figure whether there is any hope that they can produce power at a price."

GENERAL REQUIREMENTS OF REACTOR MATERIALS

In considering any project which involves materials, whether in the nuclear field or elsewhere, there are certain general engineering requirements which must be taken into account. These require-

TABLE I
General Engineering Requirements of Reactor Materials

Stability at Operating Temperature
Mechanical Strength
Ease of Fabrication
Availability
Cost

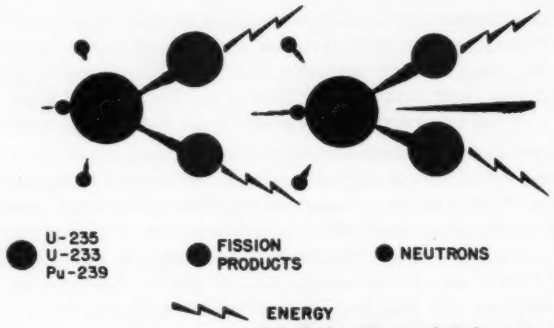
ments are given in Table I. These requirements are more or less self-explanatory and any given design must represent the best compromise which can be obtained among these factors using the knowledge which one has available at the time.

On considering the materials problems involved in nuclear power reactors, there are a number of additional factors which are of concern. These factors must be considered because of the differences between power production by conventional means and by nuclear reactors. In the conventional unit, the construction materials of the combustion chamber are heated externally. In nuclear reactors, the heat is liberated internally in the nuclear fuel. In addition, the energy changes involved in the modification of the central nucleus of an atom (fission) are about a million times greater than those involved in chemical reactions, e.g., reaction of uranium with another element or the burning of coal or fuel oil. Putting it rather crudely, we are trying to put a gallon in a teacup.

A rather interesting example of such a situation has been expressed by Ralph Lapp in the *New York Times Magazine* of August 12, 1956, in an article, "Next in Atoms: The A-Plane." A reactor, such as in the *Nautilus* is a thermal reactor which requires bulky moderating material. This is too much of a weight handicap for an airplane so that upon elimination of the moderator one is left with a fast reactor which is a rather tricky device. To quote from Lapp, "The A-plane's compact fast reactor will yield so much heat (more than that produced in the central power plant of a fair-sized town) compressed into such a small space (perhaps the size of a deep-freeze unit) as to raise the possibility that it will simply melt itself. This catastrophe haunts every reactor engineer. So the search is on for special core materials that will withstand both the intense heat and the radioactivity of the reactor core."

THE FISSION PROCESS

In essence, the purpose of a nuclear reactor is to achieve the release of the energy of fission in a controlled and usable manner. Nuclear fission (Fig. 1) is the name given to the reaction in which a free neutron, the uncharged constituent of the nucleus of the the atom, strikes the nucleus of a fissile element (i.e., one capable of fissioning) and causes it to split into two fragments of somewhat dissimilar mass. This splitting of the nucleus is accompanied by



Oak Ridge National Laboratory
Figure 1. Schematic fission process.

the release of about 200 MEV/fission. The number of fissions required to produce power at the rate of one watt is about 3×10^{10} per second. Translating this into more understandable terms, energy release at the rate of one megawatt (10^6 watts) would provide enough boiling water for about 10 to 15 cups of coffee per second.

Each fission, on the average, produces or releases about 2.5 neutrons. A self-sustaining, or continuous, fission of atoms will be possible only if at least one neutron per fission successfully causes fission in another fissile nucleus. Unfortunately, not all of these 2.5 neutrons per fission are available to propagate the chain reaction. Some are captured by the nuclei of non-fissile atoms, such as uranium-238 (U^{238}) which becomes uranium-239 (U^{239}) and decays to plutonium-239 (Pu^{239}). Some neutrons will be nonproductively absorbed in the fuel, previously created fission products, or other materials in the reactor. Other neutrons will be lost by leakage from the reactor. Consequently, neutron economy is of prime importance and is a major consideration in reactor design.

FURTHER REQUIREMENTS OF REACTOR MATERIALS

Keeping this brief outline of the fission process in mind, the reason for additional factors of concern in nuclear reactor design (Table II) becomes more ap-

TABLE II
Factors in Selection of Reactor Materials

Neutron Absorbing Characteristics
Heat Transfer Properties
Susceptibility to Radioactivity
Corrosion Resistance
Radiation Damage Resistance
Ease of Chemical Processing

parent. The neutron economy requires that the materials used in the active core of the reactor have low neutron absorption. On the other hand, control rods which operate by absorbing neutrons require high neutron absorption. The neutron absorbing characteristics are inherent characteristics of the elements.

As indicated above, heat is liberated inside the

nuclear fuel and passes outward to the coolant stream. Since the heat produced by fission is essentially independent of the nuclear fuel or its environment, this heat must be transferred at an efficient rate or the fuel will melt. This requires a material with a high thermal conductivity which also has adequate resistance to high thermal stresses.

One of the effects of neutron irradiation is to induce radioactivity in materials. Such induced activity should be short-lived with emitted gamma-radiation of low energy. If the induced activity is relatively long-lived with emitted gamma-radiation of high energy, a serious problem is encountered in maintenance and repair work and in the disposition of radioactive waste.

Corrosion resistance in nuclear reactors is more important in at least two respects than for conventional power units. Regardless of the form of fuel or coolant, precautions must be taken so that the highly radioactive fission fragments in the fuel do not contaminate the coolant. In addition, thermal gradients can cause acceleration of the corrosion rate. Corrosion in nuclear-energy work includes corrosion in aqueous, gaseous, liquid-metal, and fused-salt media. Each of these has its own peculiar problems. For instance, in the use of liquid metals as heat transfer media the phenomenon known as "mass transfer" is encountered. This occurs where temperture differences exist in a system with the structural material being dissolved by the liquid metal in the high temperature zone and being subsequently deposited in the cooler region. Another complicating factor is that corrosion rates may be altered by irradiation. This must be considered in the evaluation of the corrosion resistance of possible reactor materials.

Radiation damage may be defined as any adverse change in the physical, chemical, and mechanical properties of a material as a result of exposure to radiation. Such exposure produces increased electrical resistance, hardness and tensile strength and decreased ductility in metals. Unfilled plastics are badly affected by radiation while mineral-filled plastics (e.g., containing asbestos) are much more stable. Organic materials, in general, are about a thousand times more susceptible to radiation damage than inorganic and metallic materials.

Lastly, materials selected for nuclear fuel and/or fuel element cladding must be such that they are fairly amenable to chemical processing in order to reclaim both the unused fuel and the fission products.

COMPONENTS OF A REACTOR

Possibly a somewhat better concept of the materials problems in nuclear reactors can be gained by considering the usual components of reactors as given in Table III.

TABLE III
Components of a Nuclear Reactor

Fuel	Control
Moderator	Coolant
Reflector	Shield
Structure	

Nuclear Fuel

The nuclear fuel is of primary importance for without it there is no fission process to control. This fuel is contained in a liquid or solid matrix material which serves as a fuel vehicle or support. As indicated above, upon fissioning, the fuel gives up much of its energy of fission in the form of heat. The principal requirement of a nuclear fuel is that it must be a material capable of undergoing fission. One could conceivably write a list of desirable characteristics, but as indicated in Table IV, there are only three possible nuclear fuels. Only one of these, U^{235}, occurs naturally, the other two being formed as the result of radioactive decay. Thus, one makes use of the fuels available and makes the necessary compromises in the other materials. These nuclear fuels may be used in the form of liquid or solid metals or metallic alloys, various compounds such as oxides, as fused salts of the fuel, or as solutions in various media.

TABLE IV
Nuclear Fuels

MAJOR REQUIREMENT—FISSIONABLE MATERIAL
Possible Fuels

U^{235}
U^{233}
Pu^{239}

Moderators and Reflectors

Moderators have the function in a thermal reactor of slowing down the fast neutrons produced at fission (i.e., decreasing the energy of the neutrons) so that the neutrons may be more readily captured by the fissionable material and thereby sustain the fission process.

The purpose of the reflectors is to scatter (or reflect) as many of the leakage neutrons as possible back into the nuclear pile and thereby effect a gain in neutron economy. Both moderator and reflector

materials have the same requirements as indicated in Table V. Materials which may be useful as moderators and reflectors are indicated in Table VI.

TABLE V
Requirements of Moderators and Reflectors

High Neutron Scattering
Low Neutron Absorption
Large Neutron Energy Loss Per Collision

TABLE VI
Possible Moderators and Reflectors

Ordinary Water (H_20)
Heavy Water (D_20)
Beryllium
Graphite

Control Materials

Control of a reactor depends on maintaining the neutron balance, i.e., a steady-state neutron distribution. This control is exercised by the automatic insertion or withdrawal of a material which absorbs neutrons. The requirements of such materials are given in Table VII. None of the high neutron absorbers, such as boron, cadmium, and the rare earths (Table VIII) can be considered as high strength metals, and boron may actually be considered as more non-metallic than metallic. Since there are a limited number of possible control materials, the principal problem is to adequately incorporate such neutron poisons into fabricated bodies which meet the requirements.

TABLE VII
Requirements of Control Materials

High Neutron Absorption
Adequate Strength
Low Mass (for Rapid Movement)
Corrosion Resistance
Stability Under Heat and Irradiation
Satisfactory Heat Transfer Properties

TABLE VIII
Possible Control Materials

Boron Steel
Cadmium
Gadolinium (and Its Oxide)
Hafnium (and Its Oxide)
Samarium (and Its Oxide)

Coolants

The coolant serves as a heat transfer medium to remove the fission energy or heat of fission from the reactor core to the heat engine. This heat engine, e.g., a more or less conventional steam boiler or turbine, converts the heat into useful work. The requirements of coolant materials are given in Table IX. The coolant may be either a liquid or a gas. The possible coolants are given in Table X. Ordinary (light) water, if sufficiently pure, is always a strong possibility as a liquid coolant and is used in the Hanford and Savannah River reactors. In these cases, it acts as both a moderator and coolant. Heavy water has a distinct advantage in being able to provide greater neutron economy than light water but has the distinct disadvantage of high cost. Carbon dioxide is used as the coolant in Calder Hall power reactors in Great Britain.

TABLE IX
Requirements of Coolants

Low Neutron Absorption or Capture
Good Heat Transfer Characteristics
Low Pumping Power
High Boiling Point
Low Melting Point
Stability Under Heat and Irradiation
Corrosion Resistance
Safety of Handling

TABLE X
Possible Coolants

Water, H_20 or D_20
Liquid Metals, Na, NaK, Bi, Pb-Bi
Gases, He, $C0_2$

Shielding Materials

The function of the shield is to reduce the extraneous neutron and gamma radiation outside the reactor proper to a level which human beings can tolerate. The requirements of shielding materials are given in Table XI. Since the requirement to slow down and absorb neutrons is met by light elements and the requirement of high density to absorb gamma radiation is met by heavy elements, one finds that shields

TABLE XI
Requirements of Shielding Materials

Capacity to Slow Down Neutrons
Capacity to Absorb Neutrons
Capacity to Absorb Gamma Radiation

are normally composed of more than one material. Possible shielding materials are given in Table XII.

TABLE XII
Possible Shielding Materials

Water (H_20)
Concrete (with Special Aggregate Additions, e.g., Barytes)
Metals, Fe, Pb, Bi, Ta, W
Boral (B & Al Mixture)

In some cases, heat is generated within the shield due to the absorption of radiation. In such a case, it is necessary to interpose a thermal shield between the reactor core and the biological shield. This thermal shield may well have substantial dimensions and be made of a dense metal of fairly high melting point such as iron or its alloys.

Structural Materials

Structural materials serve to provide strength, stability, and endurance under the required temperatures, stresses, and environment. The requirements of such materials are given in Table XIII. Possible materials meeting these requirements are given in Table XIV.

TABLE XIII
Requirements of Structural Materials

Low Neutron Absorption
Stability Under Heat and Radiation
Mechanical Strength
Corrosion Resistance
Good Heat Transfer Properties

TABLE XIV
Possible Structural Materials

Aluminum
Stainless Steel
Nickel Base Alloys
Zirconium
Mg, Mo, Ti
Ceramics, Cermets

SOME REACTOR MATERIALS

A quick look at the above tables of possible materials for the various reactor components readily shows a number of elements not usually encountered in conventional practice but which are peculiar to reactors. Among these elements are boron, beryllium, zirconium, cadmium, the rare earths, and, of course, the nuclear fuels, uranium and plutonium. These may be considered as relatively new, unusual, or "exotic" metals which would probably be of little or no commercial significance if it were not for nuclear reactors. In addition, very little information about the engineering characteristics of these metals would exist if it were not for the large sums of money which have been expended by the U. S. Government. While a certain amount of information now is available relative to these metals, the lack of still more desired information leaves extensive opportunity for future investigation.

Most of these "new" metals present all the usual problems encountered in engineering practice plus a number of additional ones. The nuclear fuels, uranium and plutonium, are typical of these metals. As indicated earlier, there are no other known nuclear fuels and thus it is necessary to live with these in all their peculiarities.

Consider the case of uranium as an example of the complications which may be involved. In 1940, there was practically no information available about this metal. Today there is large scale mining and production of metallic uranium including fabrication and incorporation into finished fuel units in reactors. Metallic uranium can exist in three crystalline forms; the alpha phase (an orthorhombic structure) which is stable up to 660° C.; the beta phase (a tetragonal structure) which is stable between 660 and 760° C.; and the gamma phase (a body-centered cubic structure) which is stable between 760° C. and the melting point at 1130° C. Alpha-uranium has very pronounced directional properties, i.e., it is quite anisotropic. If there is noticeable preferred orientation of the grains, it has been found that the whole sample "grows" in a given crystallographic direction under service conditions. If the sample consists of randomly oriented grains, there is a reduction of this phenomenon which then shows up as irregularities on the previously smooth surface and is known as "wrinkling." Reduction of wrinkling and growth can be gained by obtaining a randomly oriented fine-grain crystal structure.

Conventional fabrication techniques such as casting, rolling, extrusion, forging, swaging, drawing and machining can be used with uranium and its alloys. (The phase diagrams of more than 20 of these alloys have been worked out.) At the same time, special care must be exercised in the handling of uranium since it presents a health hazard from possible irradiation of the entire body and from inhalation of its dust. Metallic uranium in massive form slowly oxidizes in air but finely divided uranium (e.g., chips and powder) is pyrophoric and thus requires special handling techniques to prevent oxidation during fabrication and machining.

Joining of uranium metal can be accomplished by welding or brazing, but the conventional techniques require modification because of the reactivity of the metal with the atmosphere. Successful welding has been accomplished by both the inert gas-shielded tungsten arc and shielded arc consumable electrode processes.

If there is high "burn-up" (fission of an appre-

ciable fraction of the fuel) in the fuel, which implies considerable irradiation, it has been found that "swelling" occurs. This is an overall increase in volume or, in other words, a marked decrease in density. It has also been observed that swelling generally increases with temperature. It is presumed that the explanation for wrinkling and growth is a partial explanation of swelling, but much work remains to be done to determine the mechanism and thus effect a cure.

Considerably less information is available with regard to plutonium, but it appears to be a considerbly more complicated metal than uranium. For instance, plutonium undergoes five changes in crystal structure as the temperature is increased from room temperature to the melting point. Thus, it is not surprising that the physical behavior is complex. One very interesting feature is a negative temperature coefficient of expansion in the face-centered cubic delta-phase of plutonium. This same phase, which would be expected to have the greatest density, turns out to have the lowest density of any of the six possible crystal phases. Plutonium is highly alpha-radioactive and violently toxic because of its strong tendency to concentrate in bone marrow where its intense radiation can cause fatal anemia.

Zirconium is another metal which has come into prominence due to its use in nuclear reactors. Because of its low neutron absorption, excellent corrosion resistance in certain environments, and relatively high strength at moderately high temperatures, zirconium is one of the better materials for structural use in a reactor. Zirconium exists in the alpha-phase (close-packed hexagonal structure) up to 863° C. and in the beta-phase (body-centered cubic structure) between 863° C. and the melting point at 1725° C. The alpha phase can be prepared in ductile form with mechanical properties and machining characteristics similar to those of plain carbon steel.

Zirconium is a case in point in which nuclear requirements have introduced a new concept of purity into selection of materials. Zirconium was nearly eliminated from consideration as a reactor material on the basis of the early published values for neutron absorption until it was discovered that the high published values were due primarily to 2 to 3% of hafnium in the zirconium. Zirconium itself was found to have low neutron absorption provided the hafnium could be separated from it. This was regarded as an extremely difficult task but one for which a satisfactory and inexpensive separation process was developed in less than two years as a result of concerted effort. Fortunately, it has been found that hafnium with its high neutron absorption possesses other characteristics which merit serious consideration of it as a control material.

HETEROGENEOUS REACTOR FUEL ELEMENT REQUIREMENTS

Because the previous discussion has been primarily of a very general nature, it might be of interest to consider the application of some of this information to a particular item of a nuclear reactor. For such an item, let us consider the fuel element in a heterogeneous reactor. In service, the greatest neutron flux, the highest temperature, and the most severe stress and corrosion conditions exist in the fuel element which is, therefore, of primary interest. The general requirements of fuel elements are given in Table XV.

TABLE XV
Requirements of Solid Fuel Elements

Adequate Strength at Operating Temperature
Stability Against Radiation Damage
Resistance to Corrosion by Surrounding Media
Good Heat Transfer Characteristics
Controlled Distribution of Fuel
Low Neutron Absorption in Cladding

In essence, the fuel element is the fissionable material—(nuclear fuel) contained in some sort of a can. The can, or cladding, may serve to locate the fuel in the reactor and to keep the fuel out of contact with the coolant. This latter requirement arises from the fact that the fissionable materials are quite chemically reactive and must be prevented from reacting with the coolant.

In fact, two of the major problems of fuel elements are those of containment and compatibility. In other words, the cladding material must contain the fuel and must be compatible with both fuel and coolant. This means that two materials must be able to exist in contact with each other over extended periods of time without chemical or metallurgical interaction. Depending on the reactor design, the cladding may be required to contain all the fission products, which would be dangerous or toxic if not contained. The fuel and the cladding must not react at the operating temperature or, alternatively, any potential interaction which might lead to leaks through the cladding must be suppressed by suitable surface treatments or the use of non-reactive interlays. Compatibility, to a large extent, is the main criterion of a suitable cladding material and limits the permissible operating temperature.

As indicated earlier, uranium tends to undergo dimensional changes under extensive irradiation. At least two approaches may be taken with regard to the strength requirements of the cladding. The first approach is to have a relatively weak cladding, thereby acting as a pliable sheath which deforms plastically. In such a case, the uranium sustains the design stresses. In view of the low strength of uranium, this approach is justified only for low temperatures, low stresses and short irradiation times. This approach requires a large amount of ductility in the cladding. The second approach requires a cladding with high strength and reasonable ductility since the cladding

supports the design stresses while acting as a mechanical restraint on the fuel. High ultimate tensile strength, yield strength, and creep strength are also desired in the cladding. If the cladding has a thermal coefficient of expansion less than that of uranium, the cladding must have sufficient strength or ductility to resist the stresses induced by a change of temperature.

MTR-TYPE FUEL PLATE

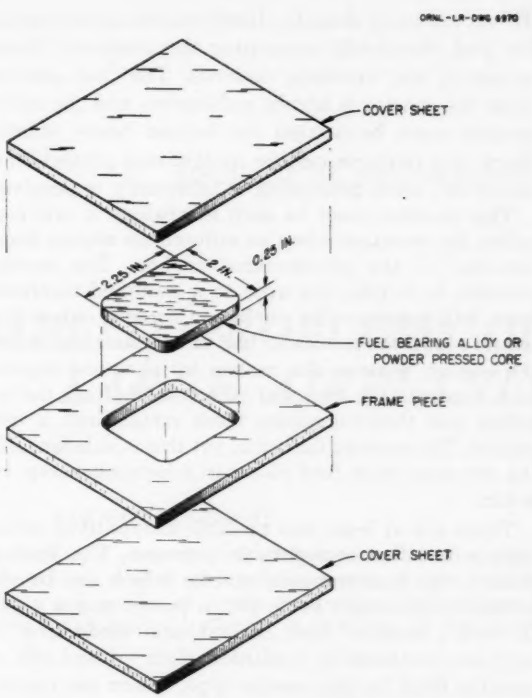
A common example of the type of fuel element discussed above is the MTR-type fuel plate. The name is derived from the original development for use in the Materials Testing Reactor at the National Reactor Testing Station in Idaho. These original plates were composed of a uranium-aluminum alloy and clad with aluminum. Similar type plates composed of UO_2 dispersed in an aluminum powder matrix clad with aluminum were used in the Geneva Conference Reactor.

In principle, the fabrication of these plates is not too difficult but is subject to the limitations discussed above. If the alloy method is used, considering the MTR plate as an example, high purity aluminum and uranium metal are alloyed directly in the molten state in a crucible with the size of the melt being restricted by critical mass limitations. The molten alloy is poured into molds to produce slabs for rolling into strips. Alloy blanks or fuel plate cores are punched from the strip by conventional stamping procedures. If the powder method is used, the fuel bearing core is produced by essentially standard powder metallurgy techniques.

Each fuel bearing core is completely jacketed by the picture frame technique. An exploded view of this is shown in Fig. 2. The composite plate assembly is thoroughly heated and hot rolled through six separate hot passes to yield a total reduction in thickness of 84%. This achieves a sound metallurgical bond between the fuel material and the cladding.

After flux-annealing (to prevent formation of objectionable blisters which may occur on subsequent processing or during service) the plates are given a further cold rolling reduction to nearly final thickness. All acceptable plates are examined under an X-ray fluoroscope to locate internal defects, determine straightness and delineate the fuel bearing section of the plate. After rough shearing, the plates are stacked and batch machined to final width and thickness.

Initial use of aluminum as cladding for uranium indicated a problem in compatability. In other words, there was metallurgical interaction between the aluminum cladding and the uranium with an intermetallic compound, UAl_3, being formed by direct attack. Rupture of the cladding was caused by local deformation due to the volume change associated with the formation of this relatively low-density compound. This problem was solved by using a layer of an aluminum alloy containing silicon between the plate core and the cladding. This interlay acted as a diffusion barrier thereby inhibiting formation of the UAl_3 compound.



Oak Ridge National Laboratory

Figure 2. Exploded view showing makeup of composite fuel plate prior to rolling.

SOME ECONOMIC FACTORS

One major factor which has not been discussed so far is the item of cost. Obviously, power can be produced from nuclear reactors. At the same time, the main problem is one of reducing the cost to the point where the power produced is economically competitive with other energy sources. Even though this is outweighed by other considerations in military applications, it is still important to the military. Since many of the major problems lie in the field of materials, the metallurgists and ceramic engineers in addition to the chemical engineers (and others) are directly concerned with costs. Apart from capital and operating costs, there is the cost of the actual fuel burned which has been estimated to be \$15 to \$30 per gram of U^{235}. In addition, there is the cost of fabricating the fuel plates and assembling them into fuel elements such as are used in the MTR and other reactors.

In operation, when a certain portion (about 25%) of the U^{235} has fissioned, the fission products constitute too large a burden on the neutron economy, and the fuel element must be replaced. The remaining uranium in the fuel plates must then be separated from its fission products and recovered for reuse.

This is normally done by dissolving the entire assembly and chemically separating the uranium, fission products, and cladding material. The fuel element from the reactor is highly radioactive and the entire process must be carried out behind heavy shields. Since this requires remote control and protection of personnel, such processing is inherently expensive.

The situation may be seen in analogy if one considers the situation when an automobile engine needs removal of the accumulated carbon. The normal practice is to take the auto to a qualified mechanic who will remove the carbon. Consider what this would cost if the mechanic had to completely dissolve the engine, remove the carbon by chemical separation, separate the iron and other metals from the solution and then reprocess these metals into a new engine. This sounds fantastic, yet this is substantially the situation with fuel plates in a heterogeneous reactor.

There are at least two possible alternatives which appear to offer considerable promise. The first of these is the homogeneous reactor which can be visualized in principle as "a pot, a pump, and a pipe". In such a reactor, fuel, coolant, and moderator (if any) are combined in a solution, slurry, fused salt, or metallic fluid. In this reactor type, fission gas reactor "poisons" (such as Xenon with its enormous appetite for neutrons) could be readily removed. The problem of wrinkling, growth, and swelling encountered in the solid fuel would be eliminated. A reactor of this kind would offer the possibility of continuous (or frequent batch) chemical processing, minimizing poison problems, and allowing complete burn-up of the fuel. In addition, the system is inherently stable. Thus, no control or safety rods are required, with control being exercised by regulating the concentration of fuel in the reactor core. Such a reactor has been operated on an experimental basis.

The second possible avenue is to use a "breeder" or "converter" which can be either a heterogeneous or a homogeneous reactor. In such a reactor, the excess neutrons which are released during fissioning (i.e., the excess over those necessary to sustain fission and those unavoidably lost) are used to produce new fissionable atoms. Such a reactor would make fuel just about as fast as it burned it. If a reactor of this type can be built and operated, then the cost of fuel would be almost completely dependent on the cost of metallurgical fabrication and chemical processing. This type of reactor is theoretically possible, and we know that the required transmutation of the elements is possible, since plutonium-239 and uranium-233 are produced in this manner. This type of reactor has been successfully operated on an experimental basis.

Lest anyone be deceived, neither the homogeneous reactor nor the breeder reactor affords a simple solution. Each of these involves a large number of problems of many types other than those of materials, and there are plenty of the latter! Many of these material problems are essentially the same as discussed in the earlier part of this presentation. In other words, it is primarily a matter of degree rather than kind.

POSSIBLE FUTURE TRENDS

As to the future, it is expected that the achievements yet to come will probably be less spectacular than those of the past 15 years, unless unexpected vistas are opened up by new discoveries in physics. The principal task appears to be one of alloy development, improvement, fabrication, and cost cutting. Radiation and corrosion damage studies will continue to be important and will no doubt yield significant advances. The future of industrial nuclear power depends on economics and even military uses will be affected by economic considerations. Nuclear power for non-military uses must be made competitive with conventional power sources. The solution of the problems of cost reduction and increased performance is principally in the hands of engineers and metallurgists.

The reactor selected for Pennsylvania Power & Light's projected atomic power plant is a homogeneous-type in which the fissionable material is contained in a slurry in the reactor circuit. A pumping system will circulate the slurry between the reactor and a steam boiler, with the rate of fission controlled by varying the level or amount of slurry in the reactor. The estimated thermal efficiency will be about 27.5 per cent.

"MECHANICAL ENGINEERING"

HIGH-SPEED PROBLEMS OF LARGE AIRPLANES

ACKNOWLEDGEMENT

This is a condensed version of a paper presented before the Aviation Conference of The American Society of Mechanical Engineers, in Los Angeles on March 14-16, 1956. It was published in the September 1956 edition of "Mechanical Engineering." The author is George S. Schairer, of the Boeing Airplane Company.

IN 1956 THE TERM "high speed" has a current meaning which starts at about the speed of sound and goes up to speeds two to three times that of sound. The word "airplane" denotes a winged vehicle flying in the atmosphere. The term "large" denotes not only a vehicle substantially larger in dimensions than the small vehicles available, but also infers that the vehicle will spend substantial periods of time at its high speed. In addition, the term usually denotes an interest in the economics of the airplane in carrying a large pay load a long distance. It is for uses such as commercial transports that the author directs the discussion of high-speed airplanes. This means that the airplane is designed with full attention to all details which permit long-range operation.

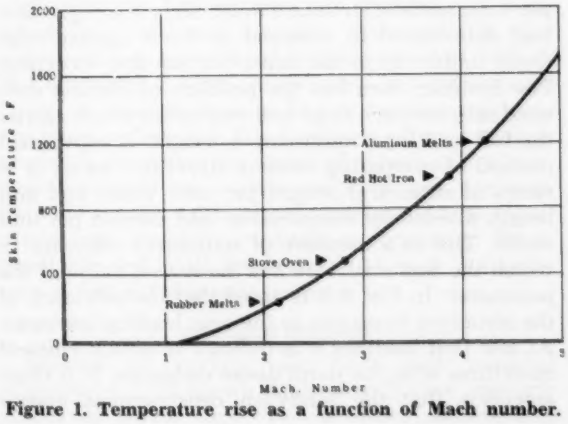


Figure 1. Temperature rise as a function of Mach number.

ATMOSPHERE

An examination of the atmosphere in which this high-speed large airplane will operate will point up the source and nature of many of the problems to be encountered (Mach number, indicated air speed, and total temperature). If high-speed flight is attempted at low altitudes, very high indicated air speeds result. However, by flying at altitude the indicated air speeds can be kept to values consistent with present-day experience. Above 35,000 ft., Mach number and true air speed are almost interchangeable in significance in discussing high-speed flight. Total temperature is the temperature encountered in bringing the air to rest at some portions of the airplane. Many parts of the airplane subjected to boundary-layer temperature will be at a temperature rise of only 84 to 90 per cent above ambient. In Fig. 1 the temperature rise at the bottom of a turbulent boundary layer assumed at 90 per cent of total temperature rise is given as a function of Mach number. This is a graphic demonstration of the temperature problem, the most obvious barrier to increasing speeds in airplanes which fly in the earth's atmosphere.

MATERIALS

A great many papers have been written in the past two years on the subject of high temperature and what it means to the structures and materials engineer. The following comments will be directed primarily toward those problems which the airplane designer encounters.

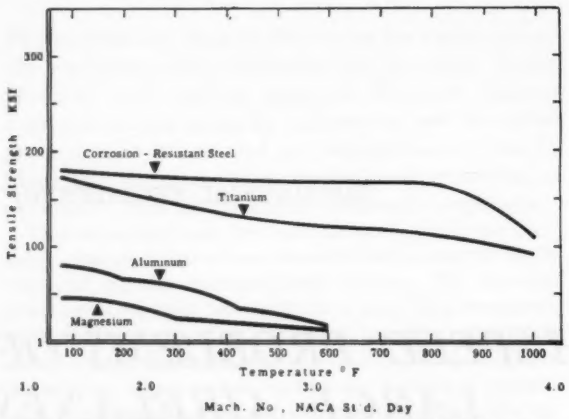


Figure 2. Tensile strength of various materials versus temperature.

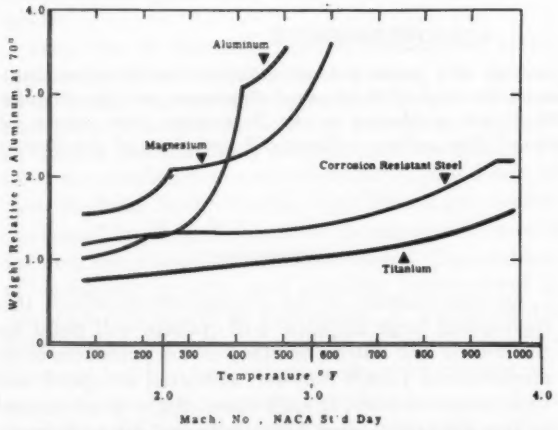


Figure 3. Relative weight versus temperature based on tensile strength.

In Fig. 2 it is seen that the short-time tensile properties of all materials decrease at high temperatures and that aluminum and magnesium encounter a major deterioration at about Mach number 2. Both titanium and steel have retained most of their strength at temperatures to be encountered up to Mach number 3.0. Fig. 3 presents the relative weight which must be used to carry a given tensile load. It is interesting to note that on a tensile basis titanium is the lightest material over the entire temperature range. Magnesium is noncompetitive and steel has properties approaching those of titanium.

The airplane designer is likely to encounter many applications where parts will be designed by low-speed low-temperature flight conditions. It is very important to understand the low-temperature properties of materials after they have been subjected to high temperatures for prolonged periods. In Fig. 4 no deterioration is evident in the titanium alloy. In the case of aluminum the high-strength characteristics cannot be counted upon at low temperatures after prolonged heating, and aluminum becomes a

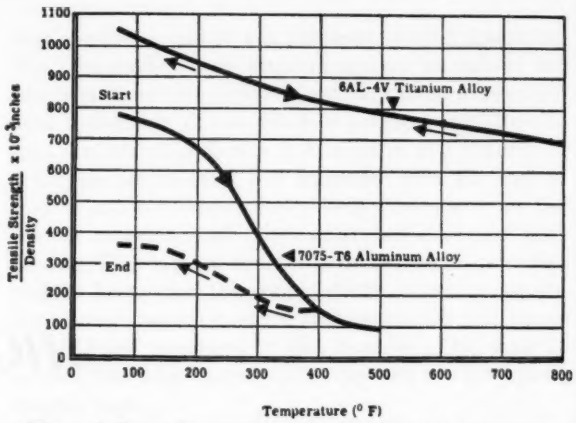


Figure 4. Strength recovery after heating (500 hr exposure time).

dubious material for use at speeds much above Mach number 2.

The modulus of elasticity plays a major role in determining the strength characteristics of composite structures subjected to compressive loads. The modulus is of utmost importance to the flutter and dynamics engineer. He is interested in the deflection which a structure will undergo when loaded, and the natural frequency of these structures. For common structural materials being considered for high-speed airplanes all suffer a deterioration of stiffness with increasing temperature, and aluminum and magnesium lose their stiffness at temperatures where their strength properties deteriorate.

STRUCTURAL DESIGN

The airplane designer finds that a substantial portion of the weight of an airplane structure is critically designed by compressive loads. The simple properties of materials as discussed in previous paragraphs do not apply directly to designing for compressive loads. Sheet-metal structures with thin skins incorporating conventional skin stiffening subjected to light compressive loads are incapable of developing unit stresses approaching the tensile strength of the material. Typically, to a first approximation the upper wing surface structure must carry a compressive load determined by external air loads applied relatively uniformly to the upper-surface skin structure. The designer then has the problem of placing stiffened skin between front and rear spars which carries the full load for a minimum of weight. A convenient method of comparing various structural forms is in terms of structural weight per unit width and unit length divided by compressive load carried per unit width. This is a measure of structural efficiency in which the best structure has the lowest value of the parameter. In Fig. 5 it is noted that the efficiency of the structure improves as the unit loading increases. At low unit loadings it is difficult to obtain efficient structures with the more dense materials. It is characteristic that the sandwich constructions appear

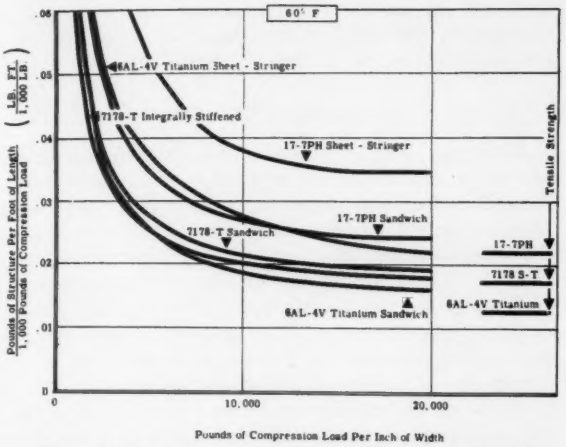


Figure 5. Efficiencies of structural panels in compression at 60° F.

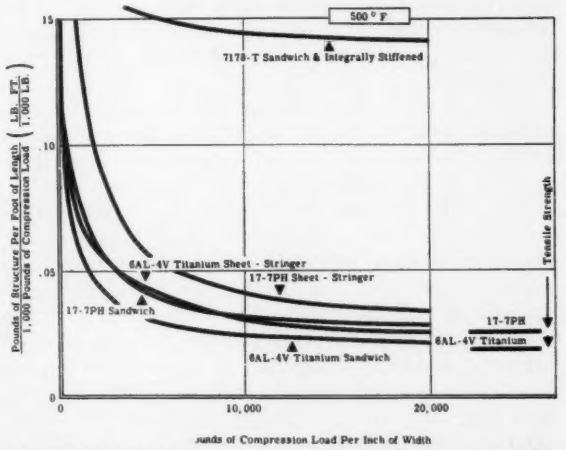


Figure 6. Efficiencies of structural panels in compression at 500 F.

most desirable when using the denser materials. In fact, sandwich structures are an attempt to reduce the effective density of the material.

The high-speed airplane must sooner or later contend with the high-temperature problems of high-speed flight. In Fig. 6 the same structural-efficiency considerations are plotted for structures at 500° F. The efficiency of titanium and steel has not changed in any unexpected fashion. The aluminum structures are more or less out. Fig. 6 again confirms titanium sandwich for structures designed at high or low temperatures over the entire range of unit loadings. Suitable titanium alloys and methods of their fabrication into workable sandwiches appears to be an inevitable and most important, materials, manufacturing, and development problem.

STRENGTH DIAGRAM

Because of varying air loads and material strengths, a high-speed airplane will have strength properties which vary over its entire altitude and speed range. As speeds increase, the angle of attack decreases and the lift distribution will become sensitive to deflections of the wing. Most swept-back structures will tend to unload by decreasing the angle of attack of the outer portions of the wing. The strength of the structure decreases at high Mach numbers owing to increasing temperature. This decrease in material properties occurs in a region where the loads applied also may be decreasing so the resultant strength characteristics of the airplane can have some unexpected characteristics.

In Fig. 7 it is seen that the limit strength of the airplane wing increases with Mach number to just below the speed of sound at which point the allowable positive load factors are reduced materially. As the speed is increased further the limit strength increases and then decreases again at very high Mach numbers as the material properties deteriorate with high temperature. It is seen that the structure has its minimum maneuver strength at sonic velocity and that the next lowest point is at the low-speed stall. In this case the maneuver strength of the airplane is determined in cold structures and the high-temperature structural problem is not designing.

Maneuver strength is only one of the structural criteria. An aircraft structure must withstand the gust loads to be encountered. The load factors produced by a large gust are shown in Fig. 7. Here again, the most critical condition is at the speed of sound. In this example the structure is not designed primarily at high temperatures, but must retain good properties at high temperatures in order to be nondesigning. A thorough study of each particular airplane is necessary before the design conditions which actually determine the structure can be understood.

CREEP

At elevated temperatures most materials become somewhat plastic and a phenomenon known as

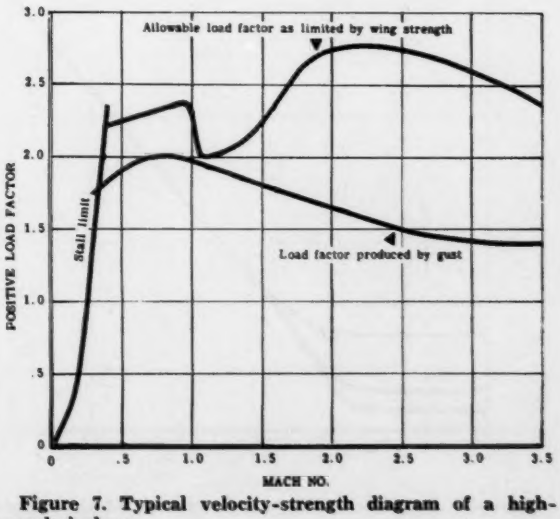


Figure 7. Typical velocity-strength diagram of a high-speed airplane.

"creep" becomes important. Thus a wing will be subjected to permanent upward deflection following long positive loads at high temperatures. The rate at which permanent residual creep deflections are encountered is dependent upon the material, loading time, and temperature. It is evident that the rate of creep and the residual permanent creep deflection increase materially with the load carried. Large airplanes normally operate at significant stress levels, and creep in the structure may become an important designing condition. An airplane cannot withstand unlimited amounts of permanent creep deflection without assuming an absurd shape which will have a major influence on the functioning of its systems and its ultimate usefulness. The designer must establish criteria of allowable creep deflection which probably must be considerably smaller than 0.001 in. per in. This will require that the stresses at high temperatures be kept quite modest and may limit the duration of high-temperature flying hours.

NONSTRUCTURAL MATERIALS

The basic metallic structure is only part of an airplane and all other portions must be considered when designing to operate at high temperatures. Some of the materials of airplane construction must be cooled to acceptable limits. The most inflexible item of airplane equipment, if he may be so called, is the pilot and the other human beings aboard the airplane. The human body has the poorest tolerance to high and low temperatures of almost anything in an airplane. Serious consideration must be given to temperature-conditioning many other items such as the tires, since high-temperature rubber substitutes suitable for tires may or may not be developed by the time one wishes to fly at very high Mach numbers. In the design of large high-speed airplanes much effort will be required in the development of efficient light methods of temperature-environment-conditioning equipment for the various items where high-temperature materials cannot be used.

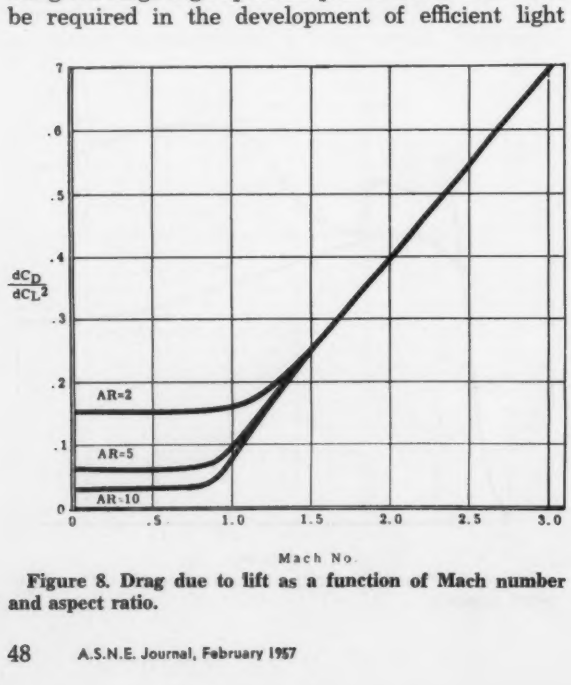


Figure 8. Drag due to lift as a function of Mach number and aspect ratio.

AERODYNAMIC PROBLEMS

Although the structural and high-temperature problems of high-speed airplanes have been highlighted in recent months, the aerodynamic problems remain quite tremendous. It must be assumed that the performance efficiency of a large high-speed airplane is of utmost importance since this is quite controlling in determining the amount of fuel and weight of power plant required to propel an airplane at high speed. The designer of the large airplane must, by definition, place great emphasis on the choice of features which will permit a low drag at high speeds. At supersonic velocities an increment of wave drag is added which is roughly proportional to the square of the thickness ratio. It can be expected that high-speed airplanes will be designed with the very lowest possible thickness ratios. Induced drag, or more strictly the drag which varies with lift, is also very important.

Fig. 8 presents the variation of drag with lift as a function of both Mach number and aspect ratio. In subsonic aerodynamics high aspect ratio is of little significance in determining the drag due to lift. Quite evidently, therefore, it can be expected that airplanes designed to fly at high Mach numbers will use relatively low aspect ratios, and the aspect ratio will be chosen almost entirely on the basis of considerations of subsonic flight. The high-speed airplane is likely to have somewhat poorer lift-drag ratios at subsonic speeds as compared to present-day equipment. This is shown quite clearly in Fig. 9. It is evident that the airplane designed with the low aspect ratio and low thickness ratio for flight at high Mach numbers will have a better lift-drag ratio at high Mach numbers than the typical present-day high-aspect-ratio high-thickness-ratio airplane. The difference at high Mach numbers is of several orders of

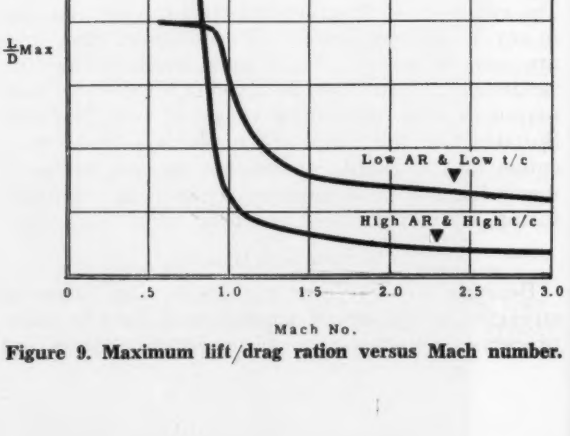


Figure 9. Maximum lift/drag ration versus Mach number.

magnitude. Since, to a first approximation, the range of an airplane is proportional to its lift-drag ratio, it can be anticipated that the airplane designer will have great difficulty in obtaining long ranges from his high-Mach-number airplane design.

FLYING CHARACTERISTICS

The aerodynamic design of an airplane is not all in the more glamorous performance features. The flying characteristics of an airplane are similar to the structure of an airplane in that they attract notice only when there is a failure. The large high-speed airplane will operate under conditions which open up many new stability and control design problems. Only a very few of these can be treated. One characteristic is a reduced aspect ratio. Aspect ratio appears as a major term in nearly all stability and control considerations. A large reduction in aspect ratio can very well require an entirely new approach to many stability and control problems. Typical of this is the down-wash problem. The down-wash produced by a given angle of attack of an airplane wing increases as the aspect ratio is reduced. If the down-wash angle is equal to the angle of attack, no variation in tail load with airplane angle of attack will be experienced and the horizontal tail will not contribute to the longitudinal stability. This may very well result in horizontal tail locations in unusual places, and in some cases in the elimination of the horizontal tail surface.

In some circumstances, supersonic aerodynamics provides solutions which differ quite diametrically from subsonic aerodynamics. Characteristic of subsonic aerodynamics is an influence of aerodynamic surfaces on the air flow well ahead of the surface. Conversely, in supersonic aerodynamics there is very little influence of airplane surfaces upon the air flow forward of the surfaces. A very important example of this is the case of control surfaces. In the subsonic case, the loading is more or less triangular both forward and aft of the control-hinge line. A high per cent of the load change caused by control deflection occurs on the fixed surface forward of the movable control surface. The load aft of the hinge of the movable control surface is effective at about one-third of its chord. In supersonic aerodynamics, very little, if any, of the influence of control deflection is felt on the wing forward of the hinge line. Nearly all of the change in load occurs on the movable control surface itself, and this load is centered at 50 per cent of the movable surface chord. The implications of this are quite far-reaching in the design of large supersonic airplanes.

First of all it is evident that a given-size control surface will provide very much less control in supersonic flight than in subsonic flight. Furthermore, the hinge moment about the control-surface hinge will be very much greater in the supersonic case than in the subsonic case and the control will be very much more difficult to balance since the pressures available

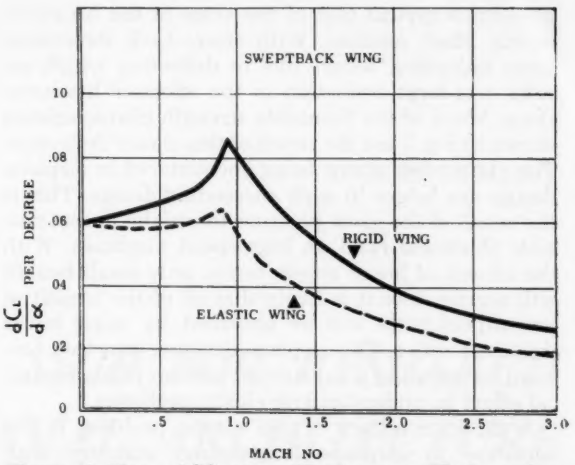


Figure 10. Slope of lift curve $dC_L/d\alpha$ versus Mach number.

for balancing are less. This higher hinge moment combined with the reduced effectiveness will be a major problem in high-speed airplanes. The use of tabs to move the control surface and to balance them is also in question since the nature of the aerodynamics is such as to reduce materially the tab effectiveness under supersonic-flow conditions. Much ingenuity will be required and many designs will be tried before a new pattern of supersonic-control design is adopted.

Of major importance in determining the characteristics of high-speed airplanes is the response of aerodynamic surfaces to changes in angle of attack. The variation in lift coefficient with angle of attack experiences large changes over the range of Mach numbers covered by high-speed airplanes. Fig. 10

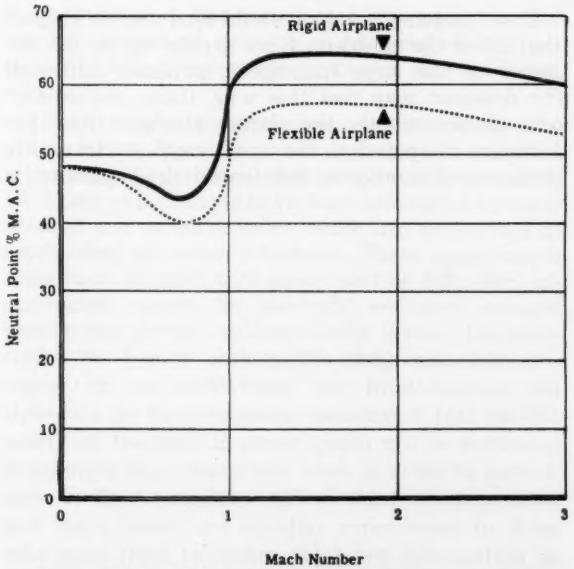


Figure 11. Longitudinal-stability neutral point versus Mach number.

presents a typical plot of the slope of the lift-curve versus Mach number. With swept-back structures, large unloading occurs due to deflection which results in a large reduction in the effective lift-curve slope. Much of the favorable strength characteristics shown in Fig. 7 are the result of this elastic deflection. The elastic deflections being encountered in airplane design are larger in each succeeding design. This is the result of the great pressure to use the lowest possible thickness ratio on high-speed airplanes. With the advent of lower aspect ratios, only small benefit will accrue since it is likely that all of the benefit of low aspect ratio will be absorbed by using lower thickness ratios. The airplane designer can look forward to spending a substantial portion of his technical effort in understanding elastic problems.

A direct corollary of the elastic problem is the variation in airplane longitudinal stability with speed. In swept-back airplanes the same deflection which reduces the loads carried by a wing at high dynamic pressures also reduces the longitudinal stability. Fortunately, in supersonic aerodynamics the aerodynamic center is in the vicinity of 50 per cent chord as contrasted to 25 per cent chord for subsonic aerodynamics. The result for a typical swept-wing airplane is shown in Fig. 11 where the neutral point for an assumed rigid airplane and its more realistic flexible characteristics are shown. A large gain in longitudinal stability occurs when going through sonic velocity. Otherwise, due to inflection, there is a continual reduction in longitudinal stability as the speed increases. The designer of large high-speed airplanes has always had great difficulty in providing adequate stability and control. It is evident this problem will worsen in the future.

SOME ADVANTAGES

The foregoing account would lead one to suspect that all of the problems have ganged up on the designer of the large high-speed airplane. Although the designer may feel this way, there are numerous places where the large airplane has advantages compared to the small airplane. In supersonic aerodynamics a substantial drag penalty is encountered in providing internal volume. At constant wing loading the wing area, and hence gross weight, varies with the square of the linear dimension, but the internal volume varies as the cube. Hence the large airplane can more conveniently enclose its gross weight or can operate at a higher wing loading. This effect will most certainly favor the aerodynamic efficiency of the large airplane. It will be more convenient to enclose the fuel and other equipment in the large airplane.

The cooling problem also will be better in the large airplane since the mass goes up with the cube of the dimension and the area subjected to heating goes up as the square of the linear dimension. Actually, it is as a result of these many scale and size effects that the large airplane is able to have a substantially larger range and pay-load carrying efficiency than the small airplane.

SUMMARY

In summary, the large high-speed airplane will operate at high temperatures and high Mach numbers. Great emphasis will be placed on the development of titanium structures with sandwich arrangement. Temperature problems will be important in all materials used in airplane construction. Aerodynamic arrangements will lead toward lower aspect ratios and very much lower thickness ratios. These combined effects will give great difficulty in obtaining long ranges. The arrangements used in high-speed airplanes will result in entirely new stability and control problems and much emphasis on flexible airplane problems. Flutter will be a major problem. Many scale and size effects will be encountered which favor the large airplane.

Other problems, not touched upon, are: choice of power plant, design of power-plant inlet and exit, mounting of the power plant itself, design of the windshield and navigation equipment, the avoidance of collision, the provision of adequate low-speed flight characteristics, the reduction of power-plant noise. All are of equal importance to the items covered in this paper.

ROBERT TAGGART

A SHIP FOR RESEARCH IN NAVAL ARCHITECTURE

THE AUTHOR

graduated from Webb Institute of Naval Architecture in 1942. He has served with the Consolidated Steel Corporation, the U.S. Maritime Administration, the Naval Research Laboratory, the U.S. Army Transportation Corps, and the Bureau of Ships. He has had extensive experience in ship model tests and in conducting and analyzing ship trials and tests. He is presently Director of the Experimental Test Division of Reed Research, Inc. This article is an adaptation of a research proposal submitted by Reed Research to the Bureau of Ships.

INTRODUCTION

Since William Froude's classic *Greyhound* experiments, the history of naval architecture is highlighted by a series of investigations which have been carried out on full scale ships. Rudder trials on the *Sterrett*, propulsion, maneuvering, and stabilization trials on the *Hamilton*, standardization trials on the *Clairton*, strength trials on the *Preston* and *Bruce*, seaworthiness tests on the *San Francisco*, structural tests on the *Philip Schuyler*, *Ocean Vulcan* and *President Wilson*, resistance tests on the *Lucy Ashton*, and dynamic stability tests on *Albacore*, to mention a few, have resulted in major advances in the science of ship design.

It is axiomatic that solution of the many new and continuing problems which confront the profession is highly dependent on a continuation of this rigorous full scale testing procedure. Although many model-test techniques and the fundamental theories of ship behavior have been greatly refined, full scale confirmation on a selective sample basis seems to be imperative. In addition, there are some ship problems which cannot be solved, or even approximated, by theory or by use of models.

The major problem facing the naval architectural profession today is seaworthiness of ships. Under this generalized heading are included the important subjects of the strength of a ship in a seaway, resistance, steering and propulsion, ship stabilization, safety of life at sea, and special naval problems of even greater importance. Other problems which also require full scale investigation are thrust deduction, effect of surface roughness, directional stability, steering and turning, structural strength of hull and superstructure, cavitation, underwater acoustics, and shock and vibration.

To carry out such investigations there is no substitute for a full time research ship adequately staffed with scientific personnel and completely instrumented. Many experiments have been attempted on commercial and military ships which are committed to established operating schedules. These experiments have been plagued with every sort of difficulty: instruments cannot be securely mounted because regulations forbid welding; hulls cannot be penetrated for fear of sinking the ship; operating personnel do not understand test fundamentals and therefore do not cooperate; passengers fear for the safety of the ship if strain gages are in evidence; ships must discontinue test work in order to participate in fleet exercises. All of these contingencies, and many more, are familiar experiences to those who have tried to obtain valid test information on operating ships.

The ideal solution to these problems is the assignment of a ship for research purposes only. Navy ships manned by Navy crews cannot fulfill this requirement. The necessary crew training, upkeep and overhaul periods, recreation and leave periods, and participation in fleet exercises reduce the availability of the ship for research work to an untenable minimum. The readiness for sea requirements complicate and limit drastically the major modifications frequently required for experimental purposes. It appears that the only practical solution is the assignment of a ship to a research organization for operation in carrying out fundamental investigations.

SELECTION OF A RESEARCH SHIP

The selection of a suitable research ship for experimental studies of ship behavior is influenced by many factors. The majority of these factors are practical in nature. The ship must be large enough to accommodate the necessary scientific personnel; it must have form and power sufficient to conduct tests under a wide variety of speed conditions; to be used in rough water it must be inherently seaworthy; its propulsion system must be adaptable to a variety of test exercises; it must have the maneuverability and control necessary to perform all test evolutions.

These are all factors which must be considered, but the primary requirement is that the ship be available for assignment for extended experimental work with *no interfering operational commitments.*

With these considerations in mind, the list of available Navy and Maritime Administration vessels has been reviewed. The type which most satisfactorily fulfills all of the requirements of the envisaged experimental program is the *Navajo* class Fleet Ocean Tug (ATF). The principal characteristics of these ships are as follows:

Length, overall	205.0	feet
Beam	38.5	feet
Draft	17.0	feet
Load displacement	1640	tons
Shaft horsepower	3000	

The ship is single screw, diesel-electric drive, and is capable of a free running speed of 16.5 knots. It is equipped with a 20 ton cargo boom, a constant tension towing winch, and a large amount of salvage gear. It is of sufficient size to simulate a large ship in resistance and propulsion characteristics and yet small enough to be handled by a crew of reasonable size. It has sufficient space on the main deck aft to accommodate a small helicopter. Its length makes it ideal for conducting seaworthiness tests in a wide range of sea conditions without the necessity of extensive search for long waves. Removal of ordnance equipment and salvage gear will provide ample reserve stability for the installation of any required topside equipment.

Ships of this class are regularly being placed in reserve status and allocation of one of them to experimental work will not affect fleet readiness. The cost (estimated at $300,000) of laying up and recommissioning at a later date will be saved if one of these ships is run continuously for research purposes. It therefore appears that the Navy would stand to gain tremendously by the assignment of one of these vessels for experimental work.

It is recommended that an ATF be assigned primarily as a research ship to be devoted to experimental work of major importance to the Navy. This ship would be manned by a crew trained in trial work and would be completely staffed with the scientists and engineers required for each phase of the research program.

This ship would be utilized entirely for scientific work and should have no operational commitments beyond those necessary to carry out the testing program. Contemplated time at sea would be on the order of 60 days per year. The remainder of the time would be spent installing instrumentation and equipment to be evaluated.

Although there are numerous pressing problems in the field of naval architecture for which this ship could be employed effectively, the program outlined is limited to those which appear to be of first importance. Suggested problems are:

Seaworthiness
Ship Stabilization
Thrust Deduction
Surface Roughness

In the following sections, these problems are defined and programs leading toward their solution are outlined.

SEAWORTHINESS

Fundamental to any study of the behavior of a ship in a seaway is a knowledge of the dynamic characteristics of the sea itself. Although the static characteristics of a ship are completely definable, the dynamic characteristics which determine the response of a ship to the sea are to a great extent a matter of intelligent conjecture. To apply a logical technical basis to such conjecture, three basic phenomena must be completely defined:

(1) The seaway
(2) The response of a statically defined ship to that seaway
(3) The response of the seaway to the statically defined ship

Definition of a seaway implies not only an instantaneous pictorial view of the sea surface but a knowledge of the change of that surface with time. In addition, the dynamic behavior is influenced by gravitational forces, wind forces, and currents, the effect of all of which must be understood to completely define that complex phenomenon which is called a confused sea.

The definition of the response of a ship to a seaway is equally complex. In addition to the motions of surge, heave, sidle, pitch, roll, and yaw, which are motions of the rigid body, there must be included bending, torsion, tension, and compression, which are the elastic phenomena existing in the complicated structure of a ship.

As a ship moves through a dead calm sea it produces a wave train which is a pronounced disturbance of the water through which it moves. This disturbance is due only to forward translation. When such an effect is compounded by the motion in six degrees of freedom which a ship exhibits in a seaway, it is obvious that a much more pronounced effect will be evidenced on the surface of the sea. Detailed definition of this effect is also essential to the study of the behavior of a ship at sea.

An experimental investigation leading toward a complete definition of all of these phenomena for the case of a single representative ship is essential. The ship employed should be sized, proportioned, and powered to such a scale that experimental results can be immediately extrapolated to other designs of interest to the Navy and to the maritime industry in general.

The suggested method for defining the seaway is centered around the most recent techniques of stereophotogrammetry. A helicopter equipped with stereocameras mounted at either end of a fifty-foot horizontal boom can be used as shown in Fig. 1. The helicopter can cruise with the ship over a selected area at an altitude of 200–400 feet taking photographs at two-second intervals. The cameras can be so oriented as to give full stereo coverage over a minimum of a 400-foot square area.

The helicopter can be instrumented to record accurately its flight altitude and attitude during all photographic periods. Coordinating time signals can be telemetered to the experimental ship throughout all measurements. A detailed study of this method demonstrates that the sea surface can be defined with an accuracy of plus or minus 0.10 feet relative to the helicopter. No difficulty in operating a helicopter in this manner, even under adverse weather conditions, is envisioned. A study by the Engineer Research and Development Laboratories shows successful utilization of a helicopter for similar purposes.

Orientation of the helicopter in space presents a more difficult problem. Since the experimental ship would be included in the photographed area, it is possible to establish the position of the helicopter relative to the ship. Datum level for each photographic run can be established by altimeters, double integration of acceleration measurements on ship and aircraft, and by calculating the mean level of the sea surface from each of the stereo displays.

Determination of the change in horizontal position of the aircraft during the run can be accomplished by air speed indicator measurements and on the ship by towed logs. Oscillatory motions can be measured by accelerometers on both ship and aircraft.

The external effect of the seas on the experimental ship and of the ship on the seaway can be delineated in the same manner as that used to define the seaway itself. Stereo photographs can be taken by the helicopter cruising slightly in advance of the ship. By this means all of the surface disturbances caused by the ship can be measured and to some extent the translatory and rotational motions of the ship itself can be depicted and should tend to confirm the shipboard readings.

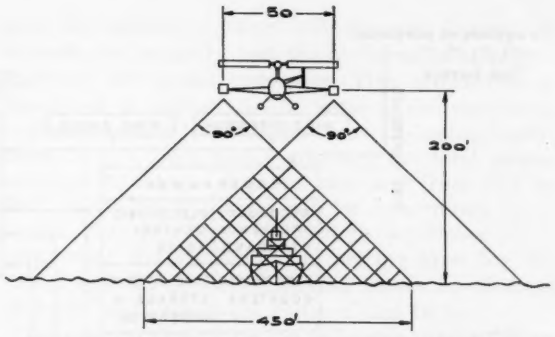


Figure 1. Position of Stereo Camera Equipped Helicopter Relative to Research Ship.

In addition, the ship can be fitted with sufficient instrumentation to explore the motions of the ship as a rigid body, the motions of the ship as an elastic body, and the effect of the seaway on resistance and propulsion. Figure 2 shows in functional form the instrumentation which would be installed in the research ship. It is not intended to be a complete delineation of all measurement systems, but to show in general the major instruments to be employed and their interrelation in the system.

The ship can be instrumented to measure the principal rigid body motions of heave, pitch, and roll. Additional instruments can be installed to measure surge, yaw, and sidle. To further define the effect of the ship on the seaway, the profile of the waves on the sides of the ship can be measured using a modified Weiss apparatus.

The elastic motions considered to be of major importance are the hogging and sagging of the ship as a beam, and local plating deflections at the bow caused by slamming and pounding. The former motions can be evaluated by fitting strain gages along the deck and house top and also along the tank top and bottom plating. The latter motions can be evaluated by fitting strain gages and deflection indicators along the forefoot and bow plating, and by a series of pressure taps to measure the fluctuation of hydrostatic pressure at the bow.

The ship would be fitted with a thrust meter and torsionmeter and recording revolution indicator. All of these instruments should be adaptable to the measurement of transients encountered as the ship passes through the seaway. Pitot logs and towed logs would also be fitted. Torque and angle recorders can be fitted to the steering gear mechanism so that the effect of holding a given heading in the seaway can be evaluated.

The basic purpose of the seaworthiness program is:

(1) to provide reliable experimental data to confirm and expand existing seaworthiness theories, and

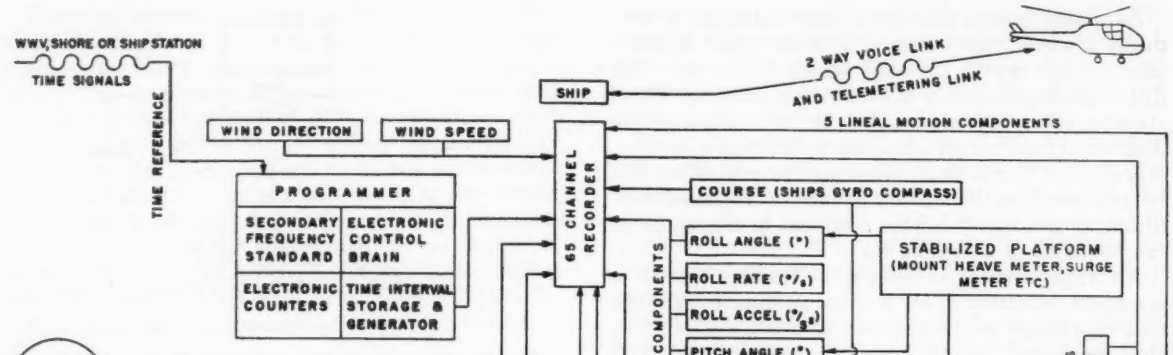


Figure 2. Block Diagram of Major Instrumentation for Research Ship.

(2) to obtain data immediately useful to the designer in developing ships for optimum performance at sea.

The ship would be equipped with the most reliable instrumentation necessary to provide all of the required experimental data. Trained scientists and technicians would be aboard to coordinate and evaluate the data which are taken, and the ship's force would be carefully selected to assure that the ship would be handled in a manner most likely to provide the desired test conditions.

This phase of the seaworthiness program would not include an exhaustive study of sea surfaces. Its principal aim would be to evaluate the ship's behavior in defined seas. Tests would be run in various types of seas which can be encountered within reasonable operating range of the home port. Representative regular and confused seas of varying wave length and amplitude would be sought.

STABILIZATION

Translatory and rotational motions ranging from mild to violent have long been considered an unavoidable concomitant of ships at sea. In their milder forms, these motions produce physical discomfort, lower personnel efficiency, necessitate additional corrections to ordnance training and elevating mechanisms, and complicate ship to shore transport. More violent motions have killed otherwise curable patients on hospital ships, maimed personnel transferring to landing boats, made gunnery impossible, shifted cargo in holds, damaged machinery, caused local hull and fitting damage, and have caused the breakup and loss of ships.

On many types of ships these motions can be tolerated. Submarines can submerge beneath the roughened surface of the sea. Cargo ships can be strengthened, personnel safety devices installed, and care can be taken in stowing cargo. Computers can be introduced into ordnance circuits to correct for ship motion. On other ships, however, a stable platform is essential. Among these are hospital ships, aircraft carriers, radar picket vessels, guided missile ships, and repair ships and tenders. On all types of ships stabilization is desirable.

Various devices for ship roll stabilization have been under development and in use for many years. Cremieu, Norden, and Thornycroft experimented with moving weight systems. Sir Henry Bessemer installed a gyro-controlled, gimbal mounted compartment on a cross-channel steamer. Schlick used a gyroscope for stabilization which was later developed into a practical device by Sperry on the *Conte di Savoia*. Thornycroft, Motora, Denny-Brown, and Sperry have developed activated fins for stabiliza-

tion. Froude and Frahm devised passive anti-rolling tanks, the latter of which were installed on many ships. Minorsky in effect activated the Frahm tanks and experiments were carried out on the *Hamilton* and *Peregrine*.

Several of these systems have shown promise, but have been discarded for a variety of reasons. It has become apparent that some sort of activated system is the only solution to the problem. The gyro-stabilizer, although theoretically excellent for roll stabilization, does not correct for yaw-heel. It must be dismissed from consideration for use on naval ships because of its excessive weight and its lethal potential in case of failure or battle damage.

At the present time the Minorsky activated anti-rolling tanks for slow speed ships and activated fins for high speed ships appear to be the most promising developments. Recently developed techniques for accelerating and arresting large weights have caused a reconsideration of the application of moving weight techniques. A great deal of theoretical work has been done on control requirements to improve these systems. Control designs are now progressing. The next logical phase of development for both of these systems is installation, test, and evaluation on an instrumented, operating ship.

Recent experiments at the David Taylor Model Basin have indicated the possibility of reducing pitch by means of fixed fins at the forefoot. These fins serve to damp the pitching motion in a manner similar to the effect of bilge keels on the rolling motion. It is entirely possible that other devices employing boundary layer control could be incorporated in these fins to improve their already promising performance.

It is recommended that the Sperry Gyrofin be installed on the experimental ship. Moving weight devices and the Minorsky anti-rolling tanks can also be tested after further development. Various types of control systems developed under Navy and commercial auspices would also be installed.

Experiments with fixed bow fins and modifications of such devices would also be carried out. In particular the longitudinal bending stresses imposed on the ship by these devices would be studied in detail.

From the internal instrumentation required for the seaworthiness program, all of the necessary information required regarding ship motion could be obtained. By the stereo photographic technique the true sea profile could also be obtained for the first time. Trained engineers would operate and evaluate the systems and recommend alterations and further simplifications and improvements which can lead to the refinement of these systems for installation on operating vessels of the Navy.

THRUST DEDUCTION

When a ship model is towed in a model basin, the force required to pull it through the water at a given speed is measured. When the same model is self-propelled at the same speed, the thrust of the propeller is also measured. The thrust force is always greater than the resistance force, indicating an interaction between the propeller and the model which tends to augment the model resistance. This interaction is expressed as one minus the ratio of the resistance to the thrust and is called the thrust deduction coefficient. It is a large factor affecting the total power required to drive a ship and can vary from 10% to 20%. Although this ratio can be determined for a model, it is extremely difficult to determine for a ship, since the application of scaling laws for the towed and self-propelled models leaves an element of doubt as to the exact value of this factor.

In order to determine the full scale thrust deduction, it is necessary first to obtain the full scale resistance. This can be done only by towing the ship or by propelling it by some method which does not affect the water flow around the hull. In addition, to completely relate the other interaction anomalies of wake fraction and relative rotative efficiency, it is highly desirable to determine open water characteristic curves for the full scale propeller.

Partial experiments along these lines have been conducted. The David Taylor Model Basin towed a tug of the YTB 500 class with propeller removed. The towing ship was an LSM fitted with cycloidal propellers in order to minimize wake and race effect on the towed ship. The British propelled the *Lucy Ashton*, an emasculated side-wheeler, with aircraft jet engines and measured the thrust required for various speeds through the water.

The former experiment did not fulfill expectations because of the effect of residual wake of the towing ship and because surges in the towline caused varying accelerations of the tug. The latter experiment, although it contributed information on full scale resistance, supplied no information on thrust deduction since the ship was never screw-propelled. The literature does not disclose any experiments conducted to determine full scale open water propeller performance.

It is recommended that full scale resistance, thrust, and open water propeller characteristic tests be conducted on the experimental ship.

Propulsion of the research ship by aircraft jet engines for full scale resistance measurements is the most desirable procedure. In the past, the lack of availability of the engines and the prohibitive cost of their installation and operation have militated against their use. However, this possibility can be explored to determine whether the situation has changed in the last few years.

In the event that jet engines cannot be used, it is believed that reliable results can be obtained by towing with another ship. If a very long nylon hawser is used, supported by intermediate floats, it is expected that the effect of tug wake and towline surge can be minimized. Measurement of speed by a strut-mounted Pitot log or towed log would eliminate the need for difficult maneuvering over a standardization trial course. If a ship of the same class as the research

ship is used as a tug, it is estimated that speeds up to 13 knots can be obtained.

Measurements would be made of towline pull, pressure distribution around the ship, and pressure distribution over the propeller disc. Measurements would be made with the propeller removed and with and without rudder.

An earlier study by the David Taylor Model Basin has indicated that on this class of ship it is feasible to remove the rudder and extend the propeller shaft clear of the hull with the addition of a single strut. By reversing the propeller on the tail shaft and running the ship astern, it can be used for full scale propeller open water characterization. The electric drive installed in the research ship permits full reverse power with complete control throughout the speed range. Slip variation can be obtained by dead pull tests and by towing barges or drags of varying resistance.

Measurements would be made of speed of advance, propeller RPM, thrust, and torque, and pressure distribution in the propeller race. The possibility of characterizing propellers of different designs and diameters can also be considered.

Full scale self-propulsion tests would be similar to normal standardization trials making measurements of speed and propeller thrust, torque, and RPM. The extended propeller shaft would be used to conduct tests of the propeller remote from the hull. Additional tests would be conducted with the propeller in the normal position with and without rudder. A jury bow rudder would be required for maneuvering.

The tests proposed above will provide information which has been vitally needed since the inception of scale model resistance and self-propulsion testing. They are essential to the verification of model testing techniques which have been in use for years and can give detailed insight into the many factors affecting the underway performance of full scale ships.

SURFACE ROUGHNESS

Roughness on a ship's hull caused by paint, fouling, rivets, plating laps, or hull openings is a major contributor to resistance. On fast, long ships this resistance accounts for as much as one-third of the total horsepower required to drive the ship through the water. Roughness of submarines and hydrofoils is an even greater proportion of the total since wave drag is virtually eliminated. The roughness resistance varies from ship to ship and at times appears to bear no relationship to the apparent roughness characteristics of the bottom.

Roughness cannot be duplicated on a scale model of a large ship. Thus, in predicting, from model tests, the horsepower required to drive such a ship, the roughness resistance is purely an educated guess.

There are two interrelated problems associated with roughness resistance of ship's hulls. The first is to obtain an understanding of those characteristics of a rough surface which influence the resistance in order that reliable predictions of full scale performance may be made. The second problem is to develop means of coating a ship in such a manner that the increase in resistance due to roughness will be at a minimum. The following program is aimed at the solution of the first of these problems.

During the last few years, an experimental program aimed at a codification of roughened plates and their related resistance has been prosecuted. This involves measurement of the resistance to flow in a test tunnel of a series of artificially roughened plates in which the roughness elements are of known height, shape, diameter, and density.

The logical sequel to this program is a series of tests of these same plates at selected sections of a full scale ship's hull. The instrumentation and test procedures which have been developed for the tunnel test program are adaptable with only minor modifications to testing on a ship. The test procedure would be in general as follows:

(1) A series of areas along the hull of the research ship would be selected where velocity distributions were known to differ. These areas would necessarily be available from within the ship.

(2) Rectangular openings would be cut in the hull in these areas and interior boxes fitted to preserve water-tight integrity. The edges of the openings would be carefully machined and test plates, mounted on flexures, would be fitted flush with the hull. The flexures would be fitted with differential transformers in the same manner successfully used in tunnel experiments to measure shear stress on the plate under flow.

(3) Pitot tubes would be fitted in each test area to determine local velocities.

(4) A series of underway tests would be conducted and the resistance of the test plates measured at different speeds of the vessel. The test plates would include smooth plates, artificially roughened plates, and plates painted with common marine finishes.

(5) These test results would be analyzed to determine relationship of resistance of smooth plates to known friction formulations; variation in frictional resistance along the ship's hull; validity of tunnel test procedures in extrapolating to full scale resistance; resistance of various marine finishes.

A second program of somewhat greater magnitude involves the measurement of the effect of roughness on the resistance and propulsion characteristics of the research ship. After completion of the work outlined under the problem of thrust deduction, this ship would be an ideal vehicle for full scale roughness experiments. The factor of thrust deduction, which has been subject to question in past attempts to relate full scale and model smooth hull conditions, would then be known. Thus, it would be possible to measure the effect of roughness on full scale resistance and relate it to model tests.

It is recommended that self-propelled tests be run with the ship painted with a series of common marine finishes. The test results would be compared with bare hull tests and with the full scale and model towing tests to determine roughness coefficients. The effect of hull openings on resistance can also be studied.

The combination of the results of the plate tests and the overall ship tests should go far toward a solution of the problem of ship roughness.

SUMMARY

The revolution in ship design now taking place within the Navy has unearthed many new and pressing problems which can only be solved by shipboard investigations. Coupled with the classical problems in naval architecture which have never been solved, the need for extensive research becomes more and more evident.

The long history of major advances which have been made by full scale investigation at sea is evidence of the logic of the contention that further experiments of this type are mandatory. To conduct such investigations there is no substitute for a full time, completely instrumented, and adequately staffed ship assigned specifically for research in naval architecture.

ACKNOWLEDGEMENTS

The foregoing article is a summary of the ideas and work of many people. The concept of instrumenting and staffing a ship primarily for research in naval architecture and the method described for the mapping of a seaway originated with Stanley F. Reed of Reed Research, Inc. The instrumentation scheme presented is that evolved by George W. Cook of the Reed Research staff. The entire experiment outlined for the full scale measurement of thrust deduction originated some years ago at the David Taylor Model Basin. Valuable suggestions and constructive criticism by personnel of the Bureau of Ships, the Office of Naval Research, the David Taylor Model Basin, the Bureau of Aeronautics, the U.S. Maritime Administration, and the Newport News Shipbuilding and Drydock Company have aided immeasurably in the derivation of a logical experimental approach to the problems presented.

A new chlorine-containing polyether plastic, known as Penton, which can withstand fabrication temperatures up to 550°F, has been developed. Of high-tensile strength, low permeability, high clarity, and high abrasive and chemical resistance, it is available only in experimental quantities at the present time.

"MAR.ENG./LOG" & "J.MAR.MARCHANDE"

THE ANDREA DORIA–STOCKHOLM DISASTER

ACKNOWLEDGEMENT

This reprint is composed of two articles. Part I is a staff article published in the September 1956 edition of "Marine Engineering and the Log." Part II was published in the August 16, 1956, edition of "Journal de la Marine Marchande," and was written by J. P. Ricard.

PART I

A SLEEK, $30 million liner lies a total loss in 220 feet of water, 50 people are dead or missing, $60 million in damage suits are in prospect—these comprise the major aftermath of the tragic collision of two luxury liners amidst fog off the New England coast late at night, July 25.

Yet, as we go to press, the incidents which led to the Swedish American Line's eastbound *Stockholm* and the Italian Line's westbound *Andrea Doria* colliding with tremendous impact 45 miles off Nantucket, have still not been made clear.

For two weeks following the incident officials of both lines maintained a tight-lipped silence to all questions concerning the navigation of the two liners prior to the collision. Then, the Swedish Line announced its version which put the blame on the Italian Line. The latter immediately refuted the Swedish account and made counter charges. The mystery, instead of being resolved, is heightened by the charges and counter charges. Neither side is in agreement on such basic points as visibility and relative position of the two vessels prior to last-minute course changes which led to the collision.

With such an impassé, only litigation proceedings in court will clarify who is to blame or the proportion of blame each vessel must assume. This may be years away.

For the 29,083-ton, 697-ft.-long Italian liner, which was to debark her 1,134 passengers at New York the following morning, the blow was fatal. She suffered a 40-ft. wide gash in her starboard side which extended from the turn of her bilge to her main deck. The heavily reinforced bow of the 12,644-ton, 525-ft.-long *Stockholm* had buried itself a good 30 ft. into the *Doria* just aft of the bridge. When the Swedish liner withdrew, she was minus approximately 60 to 70 ft. and several hundred tons of steel of her forward section.

The *Andrea Doria* developed an immediate list of 20 to 25 deg which subsequently worsened. Ten hours and 47 min. later the pride of Italy's merchant marine sank.

What happened subsequent to the fatal meeting of these two vessels will go down in sea annals as an epic in peacetime sea rescues. Of the 1,134 passengers and 572 crew members aboard the *Doria*, only 45 were lost. The crippled *Stockholm*, which played a major role in the rescue operations before limping back to New York, lost only five crewmen. Considering the magnitude of the collision and the number of people involved, the death toll was exceedingly low.

The factors which prevented this from turning into an even greater catastrophe were several:

1. The ships collided in heavily trafficked sea lanes. This enabled a sufficient number of vessels to arrive in time to effect the gigantic rescue operation.

2. The fog* which led to the collision lifted shortly afterward and the rescue was carried out in a favorable environment. It is noted, too, that the sea was calm permitting good maneuverability of life boats.

* The Swedish American Lines denies that fog prevailed at time of the collision.

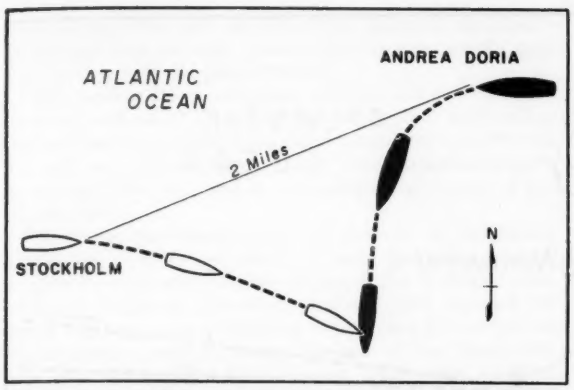


Figure 1. The SWEDISH VERSION shows that the "Andrea Doria" and "Stockholm" were on parallel east-west courses. The Italian vessel was north and 2 miles off the "Stockholm's" port bow. The collision occurred when the "Doria" turned south across the "Stockholm's" bow instead of proceeding on safe course.

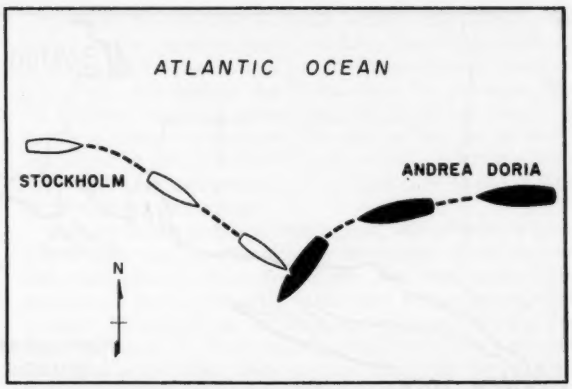


Figure 2. The ITALIAN VERSION shows the two vessels on parallel east-west courses, but places the "Andrea Doria" to the south or off the "Stockholm's" starboard bow. The "Doria" turned further south to increase the passing distance. The "Stockholm" also turned south and caused the collision.

3. The *Stockholm* did not sink, and the *Doria* stayed afloat nearly 11 hours—more than sufficient time to complete the transfer of survivors.

After the collision came the inevitable questions:

1. How did it happen and who is to blame?
2. What about the electronic miracle radar these modern vessels were equipped with to prevent just such collisions?
3. Why did the Italian vessel, widely publicized as being unsinkable, meet such an end?

The answer to question No. 1, it appears, ultimately will have to be decided in court. However, both lines give their official version of the collision. These are included herewith.

Radar, which had been considered a major factor in most speculation into the cause of the collision appears to be given a clean bill of health by both lines in their official versions.

At this writing, there has been no word from the Italian Line as to why the vessel, widely publicized as "unsinkable with two compartments flooded," sank. Therefore, we will attempt to present an objective evaluation of the vessel's compartmentation in light of the damage sustained and note factors which might have resulted in her loss of buoyancy.

If there was a wall of silence as to the cause of the collision in the days following the disaster, there were literally hundreds of opinions expressed on the manner in which the rescue was accomplished.

Newsmen greeting the rescue ships were hard pressed in making notes fast enough as survivor after survivor related his observations of the events following the collision. The crew of the *Andrea Doria* was criticized vehemently, both in highly vocal gangway interviews and in petitions drawn up aboard rescue vessels. In the main, the *Doria's* officers and crew were accused of the following:

(1) No warning of the impending disaster was flashed to the passengers, many of whom were bedded down for the night. (2) After the collision, quite a while elapsed before instructions were issued to the passengers over the loud speakers and these were in Italian. (The *Andrea Doria's* passengers comprised a large number of Italian immigrants and American vacationists.) (3) The crew outvied the passengers in entering the lifeboats. (One report stated that the first three lifeboats to reach the *Stockholm* "were filled with the Italian liner's crewmen." Many passengers evidently failed to realize that a number of crewmen were required to launch the lifeboats and to assist passenger loading and discharge on countless shuttles.)

It should be noted that many of the survivors, who gave accounts of the rescue operation, still appeared in a state of shock. And there were numerous survivors who had nothing but praise for the heroic actions of the Italian crewmen. Perhaps more significant is the fact that just about all aboard the *Doria,* who were alive after the crash, were rescued. If such a grand-scale transfer of approximately 1100 passengers off a sinking, badly listing ship was accomplished without the direction and assistance of co-ordinated ship's personnel, this was truly a remarkable thing.

When the two liners collided there was immediate shock and horror aboard both vessels. The *Stockholm's* skipper, after assessing the damage sustained by his vessel and finding her seaworthy, used good judgment in telling his passengers that he was going to lower life boats not to abandon the *Stockholm,* but to take aboard *Doria* evacuees. Reassured, the passengers of the Swedish vessel lined the rails to savor an unexpected bit of excitement.

Aboard the *Doria* there was little to offer reassurance to the passengers. The Italian liner's decks were canted in a 25-deg. list which made it extremely difficult for passengers to navigate. Yet, lifebelts had to be obtained and loved ones found and then brought up to the boat deck. Complicating the situation were passageways that were jammed with baggage and furniture that had come adrift. The fact that many were trying to go below, while others were trying to fight their way topside, added to the difficulty. But

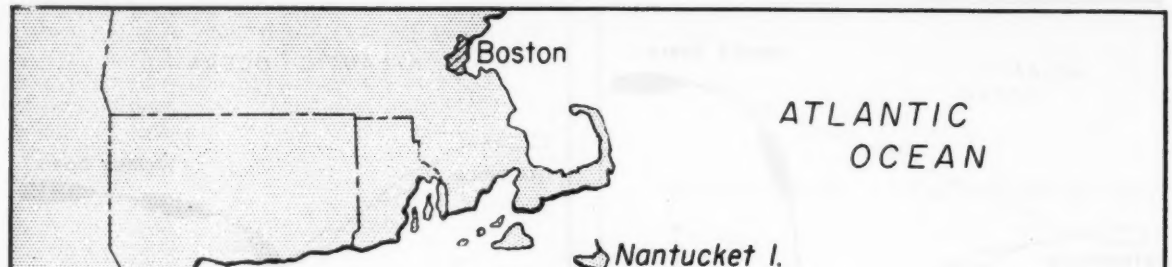


Figure 3. COLLISION POINT IN RELATION TO SHIPPING LANES. Tracks A, B and C, both eastbound and westbound, were established in 1946 agreement between transatlantic lines.

the lights stayed on and the fog lifted to show the reassuring sight of the brightly lighted *Stockholm* sending boats to the rescue. This helped to prevent mass panic. Subsequently, other vessels arrived which helped to minimize the slowly increasing list of the *Doria*.

But evacuating the Italian liner was a slow process. Her port side lifeboats could not be launched because of the severe list. Six of her eight starboard boats eventually got away, but because they hung away from the vessel (again because of the list) loading was difficult and hazardous.

One of the brighter aspects of the disaster was the manner in which other vessels responded to the SOS and carried out a remarkable rescue operation. These ranged from the French Lines *Ile de France*, which took aboard 753 survivors to the small Coast Guard cutter *Hornbeam*, which saved a few dozen people. Other vessels were the United Fruit freighter *Cape Ann*, an MSTS transport, and the Navy destroyer escort *Edward H. Allen*.

SHIP DETAILS

Built by A/B Götaverken at Gothenburg in 1948, the *Stockholm* was the first passenger liner to be constructed in a Swedish shipyard. Of 12,644 gross tons, her over-all length was 525 ft. 2 in., 69-ft. beam and a loaded draft of 24 ft. 9 in. She was designed for a loaded speed of 19 knots. Her construction featured extra strengthening against ice.

Propulsion is by two Götaverken Diesels, developing a total of 12,000 bhp. Her original accommodations were for 395 passengers divided into two classes. However, early in 1954 her interior was altered to provide for 586 passengers. She cost $6 million to build. The collision marred her 103rd crossing.

Completed early in 1953 by the Ansaldo Shipyard, near Genoa, at a cost of $29 million, the *Andrea Doria* signified the rebirth of Italy's war-ravaged shipping and shipbuilding industries. The 13th largest passenger vessel in the world, she was 697 ft. over-all with 90-ft. beam and a draft of 30 ft. Of 29,083 gross tons, she had a trial speed of 25 knots and cruised at 23 knots. Her steam turbines developed 50,000 hp. She had accommodations for 1,241 passengers in three classes, roughly half of which were tourist. Passengers were accommodated on five of the vessel's 10 decks.

She was lost on her 101st crossing, 3½ years after her maiden trip to New York in 1953.

SWEDISH AMERICAN LINE VERSION*

"The *Stockholm* picked up the *Andrea Doria* on radar when she was 10 miles away. The sea was moderate, there was little wind, and although there was haze on the horizon, visibility was good. The *Stockholm* was proceeding on an easterly course at a cruising speed of 18 knots. Proper lookouts had been posted and the watch officer was periodically checking the radar, which was operating perfectly.

"At that time the radar echo of the vessel, which proved to be the *Andrea Doria*, was bearing on the port bow at a distance of about 10 miles. Continued observations and plottings showed that the *Andrea Doria* was proceeding

* The following was set forth in a petition filed by the Swedish American Line in Federal Court, New York, on August 7 in an action to exonerate or limit its liability for damages arising from the collision.

on a course to the port, or left, of the course of the *Stockholm*, and that on such courses the vessels would pass clear port to port at a safe distance.

"The *Andrea Doria* came into sight at a distance of about 2 miles, as checked by radar. She was well to port and in the position anticipated from radar plots. She was showing her red, or port side light and her white masthead lights were open so as to pass at a safe distance to port of the *Stockholm*.

"Although the vessels were in a position to pass safely port to port, red to red, the *Stockholm* went to starboard to give even greater passing distance. The *Andrea Doria*, however, suddenly closed out her red light, showed her green light and veered sharply to her own left or port at undiminished speed, crossing the bow of the *Stockholm*. The *Stockholm* immediately went hard right and full speed astern, but it was impossible to avoid collision, and shortly thereafter the starboard side of the *Andrea Doria* and the bow of the *Stockholm* came into collision.

"Those on the *Stockholm* heard no signal from the Italian vessel until after the *Andrea Doria* veered to her left, the signal being blown just before the collision contact.

"Although the *Stockholm's* bow was severely damaged, her watertight doors were immediately closed and through the efficiency of her master, officers and crew she was saved, took aboard 572 survivors from the *Andrea Doria*, transferred 370 more survivors to other rescue vessels and returned safely to New York.

"The aforesaid damage to the vessels, loss of life and personnel injuries and the subsequent sinking of the *Andrea Doria* were not caused or contributed to by any fault or neglect on the part of the *Stockholm* or those in charge of her, but were caused solely by the fault and neglect of the *Andrea Doria*, her owners and those in charge of her in the following respects, among others which will be shown in the trial thereof:

"1. Those in charge of the *Andrea Doria* were careless, incompetent and inattentive of their duties.

"2. The *Andrea Doria* was not properly manned or equipped.

"3. The *Andrea Doria* failed to keep a proper lookout.

"4. The *Andrea Doria* was proceeding at an immoderate and excessive rate of speed under the circumstances.

"5. The radar equipment aboard the *Andrea Doria* was faultily maintained and/or operated.

"6. The *Andrea Doria* failed to sound signals as required under the circumstances by the International Rules (of the Road).

"7. The *Andrea Doria* suddenly and without warning veered across the bow of the *Stockholm* and into collision with the *Stockholm*.

"8. The *Andrea Doria* was maneuvered in a reckless and negligent manner.

"9. The *Andrea Doria* failed to stop, or to stop and reverse her engines.

"10. The *Andrea Doria* failed to take any proper or adequate measures to avoid collision with the *Stockholm*."

ITALIAN LINE VERSION

"It is not the desire or policy of the Italian Line to engage in a campaign of rebuttal of inaccurate statements concerning the disaster at sea. However, the situation now is such that it has become imperative that the public be given the true facts.

"Despite the charges of fault against the *Doria* contained in the Swedish American Line limitation petition, it is significant that it has not filed any formal claim or begun any suit against the Italian Line for damages. We are advised that the proceeding which it has begun is purely a defensive measure intended by the line to avoid the arrest of the *Stockholm* and to make everyone who has a claim against Swedish American Line to put it forward in that proceeding.

"Before the proceeding was begun, our attorneys gave notice that they would take the testimony of the master and other officers of the *Stockholm*. The beginning of the proceeding by the Swedish American Line stopped that attempt. Nevertheless, our attorneys are again asking the court for leave to cross-examine the *Stockholm's* officers in order to get what they say are the facts rather than accept the legal phrases included in the Swedish American Line's petition.

"Our attorneys, who have made a very extensive investigation of the facts relating to the collision advise me that the full responsibility of the *Stockholm* will be established. In the meantime, I should like all the friends of the Italian Line not to be disturbed by legal maneuvers and that eventually it will be established that the *Andrea Doria* was one of the finest ships ever to sail the Atlantic, was commanded by a thoroughly capable captain, had a capable and honorable crew, and had the very latest safety construction and equipment, including up-to-the-minute radar, and that the *Stockholm* was at fault for the tragic loss of life that occurred in the collision.

"The facts are that the *Stockholm* was traveling about 20 miles to the north of its proper route, directly in the path of westbound ships. The *Andrea Doria*, traveling at reduced speed in a fog for a period of 8 hours prior to the accident, had been using its radar equipment since 3:00 p.m. of the day of the accident. Although the *Stockholm* denies it, she had been traveling in fog for a substantial time also. The *Doria* spotted a vessel in its path at a considerable distance, but on a track that passed starboard, starboard to starboard, not port to port as claimed by the Swedish American Line.

"Captain (Piero) Calamai, who had been on the bridge of the *Doria* since the ship entered the fog area, changed his course to port to ensure even more room for passing, and this maneuver should have let the two ships pass in safety. However, instead of remaining on its course, or it, too, veering to port, the *Stockholm* as now is admitted by the Swedish American Line, veered to starboard and toward the *Doria* without reducing its speed of 18 knots.

"Its bow plunged into the side of the *Doria*, a distance of 30 to 40 feet.

"It is clear to us, and we are advised that the fault of the *Stockholm* was flagrant as to her high speed, her failure to sound fog signals, and her admitted change of course directly into collision. We are confident that the conduct of the officers and crew of the *Doria* will be vindicated fully."

KEY POINTS OF SWEDISH AND ITALIAN VERSIONS

Study of the Swedish American Line's charges contained in its petition, and the counter charges voiced by the Italian Line shows wide conflict over several important points.

Visibility

According to the Swedish American Line, visibility was good, despite a slight haze on the horizon. The Italian Line states that fog shrouded the area and

The following is a statement of rebuttal to the Swedish American Line's charges issued by Giuseppe Ali, general manager of the Italian Line for the United States and Canada, to the press on August 8.

that the *Stockholm* must have been traveling in fog for a substantial time prior to the collision.

Course

The Swedish version states that the two vessels were headed in opposite directions along parallel east-west courses, with the Italian vessel's track being safely to port (north) of the Swedish vessel. The collision occurred after the Italian vessel swerved (south) to its left on a course which crossed the bow of the *Stockholm*.

The Italian Line's version agrees that the two vessels were proceeding on parallel east-west courses, but notes that *Andrea Doria's* course was south of the *Stockholm's*. The Italian vessel turned south to increase the already safe passing distance only to find that the *Stockholm* executed a similar turn to the south which caused her to crash into the *Doria's* starboard side.

Tracks

The point where the collision occurred indicates that both vessels were out of the recommended shipping lanes suggested by the North Atlantic Tracking Agreement of which both lines are signators. The Italian vessel was about 5 miles south of westbound Track "C." The Swedish vessel was far north of the eastbound Track "C." At the point of collision there is supposed to be a 20-mile separation between the east-bound and west-bound tracks.

Speed

The Swedish American Line admits the *Stockholm* was cruising at a speed of 18 knots. The Italian Line statement reported that the *Doria* was proceeding at "reduced speed," but was not explicit. The Italian liner has a speed of 25 knots, but cruised normally at 22 to 23. Thus, reduced speed could even have been greater than the Swedish vessel's 18 knots. It is apparent that the announcement of the *Stockholm's* speed was conditioned by the weather and visibility conditions the Swedish vessel says existed prior to the collision.

WHY DID THE DORIA DEVELOP A QUICK LIST AND SINK?

While the actual cause of the collision of the *Andrea Doria* and the *Stockholm* has caused considerable concern as to safety of navigation, the rapid sinking of the *Doria* has posed problems to ship designers. Working only with available information that has been published previously and some natural assumptions, certain conclusions can be drawn.

Area of Damage

The photograph of the *Doria* (Figure 4) in damaged condition shows the extent of the damage. It extends from just forward of where the promenade deckhouse joins the side aft to the after side of the deck enclosure. This is for a distance of about 70 ft.

The vertical distance of the hole is not measurable. It extends downward from the promenade deck to the turn of the bilge at least. The *Doria* normally has a draft of 30 ft. and the *Stockholm* a draft of 24 ft. 9 in. Regardless of the general shape and size of the hole ripped in the *Doria's* side, it was extensive enough to cause the vessel to sink quite rapidly.

In way of this area were: First-class cabins on the upper deck; first-class cabins, chapel and foyer on the foyer deck; third-class cabins on the A deck; garage and third-class cabins on the B deck; third-class cabins, laundry and linen storage on the C deck; cargo hold, baggage storage, oil tanks and generator room on D deck, and deep tanks and cargo hold in the hold. From the A deck (bulkhead deck) to the lower decks were stair wells, ladder trunks and air-conditioning trunks.

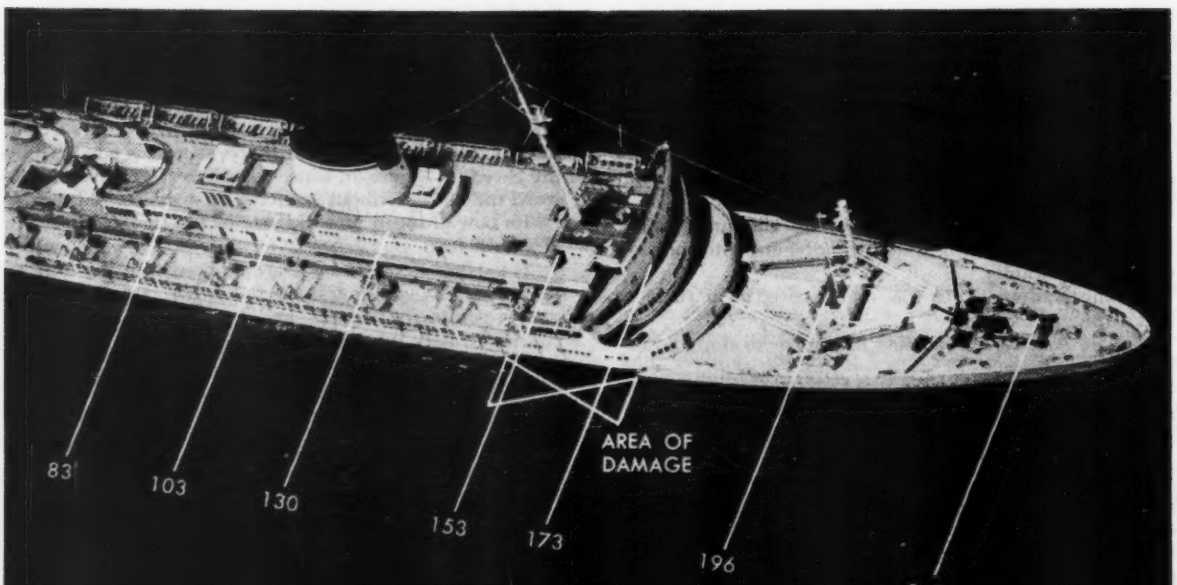


Figure 4. SINKING VIEW OF DORIA with bulkheads indicated shows extent of damage at promenade deck.

Damaged Structure

From the accompanying photograph and plans it can be seen that the bow of the *Stockholm* entered between bulkheads 153 and 173. The bow, according to reports, penetrated for a distance of 30 to 40 ft. In so doing, the damaged area took in bulkheads 153 and 173 thus flooding three compartments.

The damage to bulkhead 173 may have been limited to the area above the waterline, however, with the listing of the vessel such an area would have gone below the damage waterline. From the collision accounts filed by both steamship lines, at the time of the collision both vessels were traveling in approximately the same direction. The force of the collision and the forward motion of both vessels would swing the port side of the *Stockholm* close to the starboard side of the *Doria*. Then in backing away from the *Doria*, the *Stockholm*, most likely, raked the *Doria* for some distance. If such happened, the wing tanks along the engine rooms would be ripped open by the jagged bow of the *Stockholm*. This would increase the instability and flooded length of the *Doria*.

The Doria had 11 transverse water tight bulkheads, arranged so as to comply with the requirements of the 1948 Convention for Safety at Sea, including the maintenance of positive stability with any two compartments flooded or partly flooded. To achieve compliance with the Convention, light-alloy metals were used extensively for the upper decks of the superstructure.

Throughout the machinery spaces, longitudinal bulkheads extend the double bottom up to deck level, giving a double-hulled ship over the midships portion.

Rapid List

The rapid listing of the *Doria* caused many questions. A study of the plans shows that deep tanks had to be pierced in the collision. Since all passenger liners refuel in the United States, where oil is cheaper than in Europe, it is assumed that the *Doria* did likewise. On this basis, the fuel tanks and fresh-water tanks were slack. A sudden flooding of these tanks would cause an immediate list which in turn put the bulkhead deck on the low side at or below the water level. Continued flooding in the three damaged compartments aggravated this condition.

If it had been possible to rapidly flood the deep tanks and inner bottom tanks on the port side, it might have been possible to correct the list. However, this would not have altered the course of events since three compartments were flooded in a two compartment ship.

Doria's Stability

The ship's stability compares favorably with other ships as is shown in Table 1 which appears in a paper presented in Genoa on September 25, 1952, at the Autumn Meeting of the Institution of Naval Architects, entitled "Six Recent Atlantic Liners," by Lt. Gen. E. DeVito, naval constructor (ret.), Italian Navy. It shows that the index of stability for the six liners of similar dimensions is almost the same. Call-kb the height of the center of buoyancy b above the keel k and bm the transverse metacentric radius, and assuming virtually $kb = 0.55$ D (draft) and $bm = 1/13$ B^2/D for all the liners considered, it was possible to get a virtual and approximate comparison of the initial stability. It was assumed that an initial metacentric height of 4 ft. was provided in all cases.

It is interesting to note that the *Independence* is also a two compartment ship. It has an over-all length of 682 ft. 6 in., 89-ft. beam and a draft of 30 ft. as compared with the *Doria* which is 697 ft. long over-all, has a 90-ft. beam, and a draft of 30 ft. However, the *Independence* is subdivided by 14 watertight or oiltight transverse bulkheads or three more than on the *Doria*.

Questions Unanswered

Many questions have been raised that could and undoubtedly will get further study. The unanswered question of whether or not the watertight doors in the area of damage were closed or left open is interesting. Available literature does not specify whether the doors were operated electrically, hydraulically

Table I—A Comparison of the Doria's Stability with Other Passenger Vessels

			Caronia	*Orcades*	*G. Cesare*	*A. Doria*	*Independence*	*America*	*T/S similar to United States*	*Bremen*
Displacement at full load		Tons	(31,200)	32,200	26,880	29,000	30,100	35,440	52,000	50,000
Draft	D	Ft	30	31	28	29.67	30	32.5	34	32
Virtual height of center of buoyancy above the keel	K b = 0.55 D	Ft	16.5	17.1	15.4	16.35	16.5	17.85	17.8	17.6
Breadth	B	Ft	91	90.5	87.27	89.91	89	93.25	101.5	101.71
Index of stability	B^2/D	Ft	275	264	273	272	264	267	302	323
Virtual transverse metacentric radius	$b\,m = 1/13\ B^2/D$	Ft	21.1	20.3	21	20.9	20.3	20.5	23.2	23.8
Virtual height transverse metacenter from the keel	$k\,m = k\,b + b\,m$	Ft	37.6	37.4	36.4	37.25	36.8	38.35	41.9	41.4
Virtual height of center of gravity above the keel, required in order to determine the initial metacentric height g m = 4 ft	$k\,g = k\,m - g\,m$	Ft	33.6	33.4	32.4	33.25	32.8	34.35	37.9	37.4
Depth at strength deck	H	Ft	70.25	66.75	65.9	67.75	61.83	73.49	(82)	79.4
Ratio	$k\,g/H$	—	0.48	0.50	0.49	0.495	0.53	0.465	0.463	0.47

or manually. From an academic point of view in this case and for future study and improvements this question should be investigated.

While the damaged area definitely took in two bulkheads thus opening three compartments, a blow such as the *Doria* sustained, even if the bulkheads had not been hit, would spring the bulkhead plates. The driving of the decks back by the bow of the *Stockholm* would have ripped brackets and such other structure in the way from the bulkheads.

Like a famous predecessor, the *Titanic*, the *Doria* was claimed to be as unsinkable as a ship could be. From these two sea tragedies, the first lesson learned is that no claims of unsinkability should be posted on any ship. In the *Doria's* case, the wing tanks and deep tanks that were thought to add to the watertight integrity of the vessel actually were a detriment. If it had not been for these, the *Doria* never would have taken such a rapid list.

The inability to lower the lifeboats on the port side has been raising many questions. The *Doria* had 16 lifeboats, carried in "Schat"-type gravity davits and lowered by eight electric winches. The lifeboats could accommodate more than 2000 people. Yet, due to the fact that those on the high side could not be lowered, there was not sufficient boat capacity. Can the method of carrying and operating lifeboats be improved to avoid a repetition of this condition?

PART II

The *Andrea Doria* disaster will lead to a certain number of inquiries and investigations, and possibly may even cause a new International Conference on Safety at Sea to be convened, the last one to be held being in London in 1948. In this domain of disasters at sea, prudence and discretion are incumbent upon the commentator, at least until such time as he has available all the results of these investigations. The writer will, therefore, take particular care not to formulate any opinion in relation to the problematic responsibilities of the two vessels involved, to the failure of radar installations or to the degree of confidence which can be placed in the use of such apparatus for the purpose of navigation in fog at full speed.

Nevertheless, there are certain facts which speak for themselves on a simple examination of the widely-published photographs of the disaster which have immediately excited the interest of the experts. Three things appear to me to be of particular importance:

(a) First, that the lifeboats on the side opposite to the list were not lowered, and it does not appear as if any attempt had been made to do so, seeing that the eight boats on the port side seemed to be completely intact on their davits up to the very last moment before the sinking of the ship.

(b) Second, that the liner would appear to have very quickly developed a pronounced list on the holed side, of apparently more than 30 deg. which, moreover, clearly explains the impossibility of having been able to use the boats on the port side;

(c) Third, is the loss itself of the *Andrea Doria* after a truly violent collision, in which it is clear she was struck amidships, the hole made appearing to affect only one or two compartments directly below the bridge. Nevertheless, the compartmentations of the ship would certainly allow it to float with at least two compartments flooded.

The first fact strongly confirms the apprehension which sailors and shipbuilders always have with regard to the possibility of getting away and lowering the whole of the lifeboats from a deck situated at a great height from the water, in spite of the improvements in davits which allow them to swing widely outwards from their center of gravity and in spite of the use of such devices as the Schat runners, for example. The proof is all the more convincing since the disaster took place in a relatively calm sea. The modern liner, widely partitioned off into compartments by its transverse water-tight bulkheads, has only a very small chance of sinking upright, by lack of longitudinal stability (that is to say by the settling down of one end), which allows the lowering into the water of the whole of the boats. There is, on the other hand, a strong possibility of it sinking, if it does sink, more or less rapidly, through lack of transverse stability. The commander will resolve to abandon ship, especially if the sea is rough and outside help is delayed, only at the last moment, and it is then infinitely possible that the list will have become more pronounced. This is the dilemma:—Present arrangements are such that the use of all the boats cannot be counted on, except in the case of a ship which sinks transversally straight by changing of the trim, but this is not very probable in the case of a liner with a large number of compartments. The only advantage of having the boats on the davits, a custom perpetuated by tradition, is that it allows the "comfortable" embarking of the passengers at the level of the promenade deck. This advantage, however, is seriously impaired when only half the passengers can benefit from the privilege of embarking in this way. The experience of the *Andrea Doria* is that, very fortunately—albeit at the not too great a cost of broken limbs and sprains—the other half was able to transfer, somehow or other, from the wrecked liner to the boats of the rescue ships. This fact is going to reinforce the arguments of those who declare that the classical lifeboats, of heavy and cumbersome build and very difficult to handle, could advantageously be replaced by rafts and unsinkable and inflatable craft, perfected in the course of the last war but which undoubtedly pose the problem of uncomfortable embarkation of the passengers, once these craft have been lowered into the water, with the aid of rope-ladders, nets, chutes, etc. In brief, it would appear that this question of life-saving must be reconsidered.

Inasfar as the second and third intimately-interconnected facts are concerned and which cannot, therefore, be treated separately, it would not appear, according to the plans of the ship, that the flooding of the damaged part and of the part adjacent thereto (if the breach coincided with a water-tight bulkhead)

could have led to an asymmetrical invasion of the sea-water. It must be admitted that the water-tight doors were closed from the beginning. This operation is sufficiently repeated during the course of a voyage for it to be considered as certain. It can also be admitted, the ship having been a certain time in the fog, that the port-holes above the partitioned deck had been closed, although it is difficult to have in this respect the same certainty. The considerable list which so rapidly developed would not, therefore, be explained, except there was insufficient stability at the moment of the collision. Once, due to a heavy list, the bulkhead deck is under water, it is no longer any use to be able to float with two, three or even four compartments flooded, as the flooding gradually extends to the other sections underneath this partitioned deck by the trickling of water which accentuates the list and the loss of stability. Too close a partitioning can even, at a certain stage of the flooding, be more damaging than helpful, insofar as, with a more widely-spaced partitioning, the massive and sudden inrush of water into the bilges would cause the vessel, at least momentarily, to straighten up. In short, partitioning can only ensure the invulnerability of the vessel for as long as stability remains sufficient to limit the list to such an angle that the bulkhead deck is not submerged. It may be further said that the height of the partitioned deck should not depend only on the degree of partitioning of the holds, but also on stability in the most unfavorable conditions of navigation. And this brings us to the difficulty of ensuring the safety of the vessel through the medium of regulations, however exacting these may be. Stability is not an unchanging constructional characteristic. It is a variable feature which depends essentially on loading conditions, that is to say, on the position of the changeable weights in the holds: merchandise, fuel, fresh water, which exercise an influence on weight stability. Now, the *Andrea Doria* was at the end of the Europe-New York crossing, after having used up all its fuel-oil and, probably, also its fresh water, and this might explain a certain lack of stability in the weights, further aggravated by the careening effects of the numerous nearly empty liquid tanks. Naturally, for the time being this is no more than a hypothesis, but it is a very likely one. It poses the problem of ballasting, diffidently dealt with in London in 1948, it being understood that this term is used with reference to navigation with more or less constant stability, achieved by filling the tanks with salt water, as and when the fuel and fresh water are used up.

The impossibility of ballasting fuel-oil tanks has been acknowledged for a long time. To do so would be to risk the avalanche of penalties incurred by any vessel discharging oily water in the docks of the Port of New York. There is also the very serious risk of combustion by reason of the impossibility of eliminating by decantation the water from a fuel-oil the density of which reaches unity. There is no possible advantage in ballasting the tanks which should contain the distilled water necessary for feeding modern boilers. As regards the ballasting of tanks containing fresh water for toilet purposes, although this is more easily admissible, it comes up against the difficulties of pollution, cleaning during calls at ports and of anti-corrosive protection of these tanks. We are convinced that the positive solution is first to produce by means of water-distillation apparatus—and these plants must be capable of amply producing the supply required—all the necessary water, whether this be for the boilers or for the toilet requirements of passengers and crew, which would considerably reduce the ballast to be provided, and then to compensate for the consumption of fuel by ballasting salt-water tanks specially provided for the purpose. It is often difficult to find in a suitable position the necessary space for such ballast tanks and, in any case, such requirements, which are not strictly enforced by any regulations, exercise a certain influence on the economic aspect of the scheme. It is quite evident that it is more economical, both from the point of view of capital investment and of running costs, to avoid the use of costly distilling plants which require delicate handling, and to transport the fresh water reserves in the tanks exclusively to be used for ballasting in the solution which we put forward. But it would certainly appear that in the case of ocean-going vessels, this is the only method which provides the certainty that the ballasting will be carried out effectively and systematically, because it does not entail any practical difficulties and because the stability of the vessel will be maintained within such limits that it will never become insufficient even in the most unfavorable conditions of loading, particularly towards the end of a crossing. It is only at this cost that a well-partitioned vessel will be rendered unsinkable.

Once again, *à propos* of the *Andrea Doria,* this is merely a simple hypothesis. But we have wanted to insist on the greater risk which may be run by the modern vessel due to changes in stability—a much greater risk than its predecessors. The technique of modern shipbuilding tends to burden the superstructure and to lighten the hull, which, in its turn, tends to reduce the weight stability. Moreover, the variations of the latter have increased proportionally to the ratio between variable weights and fixed weights. Thirty years ago the liner which allowed 150 Kgs. per horse-power for the fixed weight of its power-unit was better placed in this respect than the modern liner which does not allow more than 50 Kgs. True, it consumes one-third less fuel, but this economy is more than offset by the fact that it consumes a great deal more water, due to the more extensive use of fresh-water sanitary appliances made necessary by the modern concept of comfort and hygiene. Furthermore, the old liner could, if the need arose, take in salt-water ballast into parts of its fuel tanks, because the cylindrical boilers then used were much more suitable than modern boilers for the burning of heavily-polluted fuel oil of much lower density and easier to draw off.

There is, therefore, here an essential problem in re-

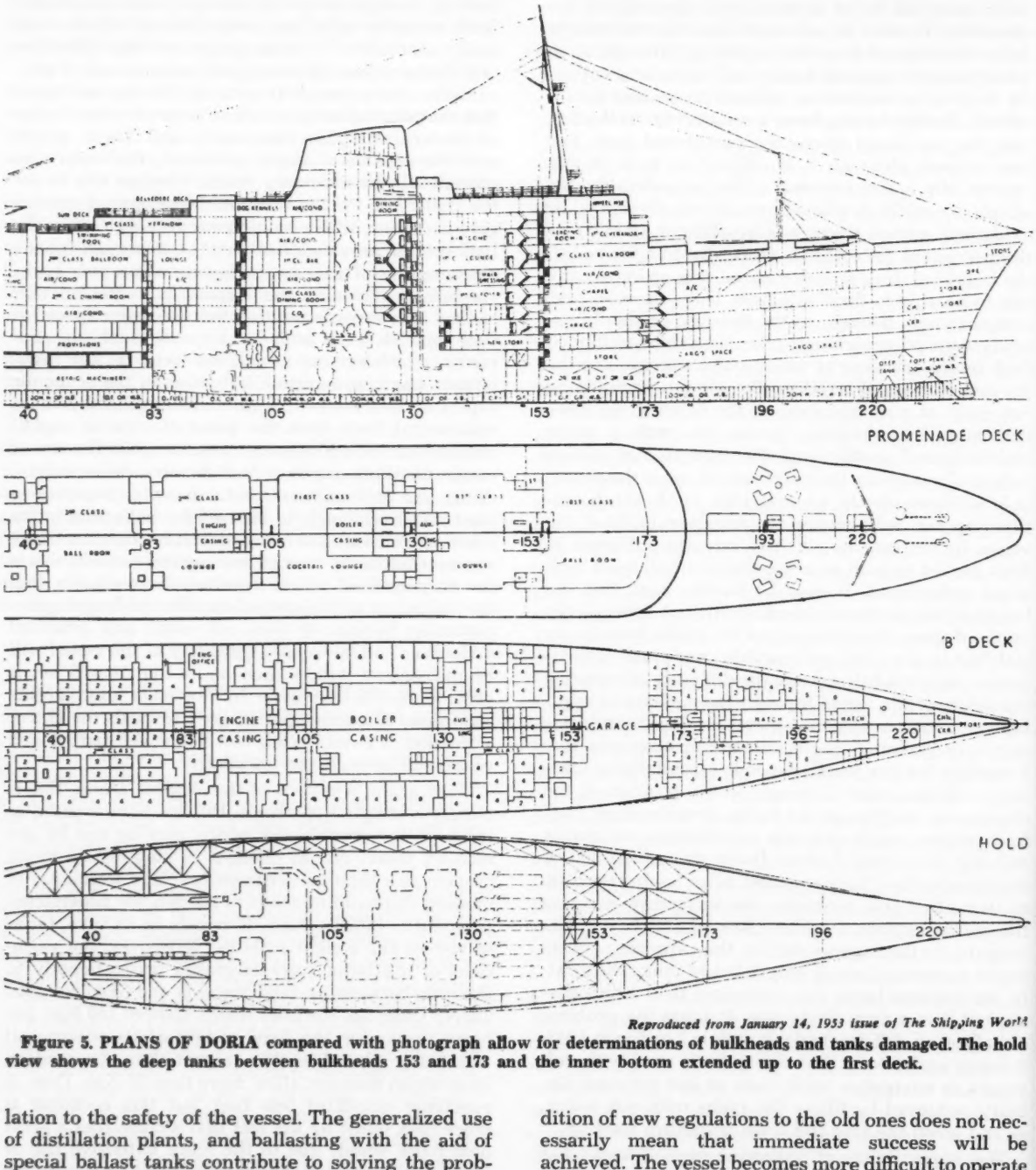


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Figure 5. PLANS OF DORIA compared with photograph allow for determinations of bulkheads and tanks damaged. The hold view shows the deep tanks between bulkheads 153 and 173 and the inner bottom extended up to the first deck.

lation to the safety of the vessel. The generalized use of distillation plants, and ballasting with the aid of special ballast tanks contribute to solving the problem at the cost of certain sacrifices. It will not be fully solved until the day when atomic power propulsion enables ships to sail at constant displacement and with a very considerable reinforcement of weight stability due to the great weight of the reactors, the intermediate exchangers and their protective shielding.

The loss of the *Andrea Doria* may perhaps take us to London again. It would be advisable beforehand that the idea should be well appreciated that the addition of new regulations to the old ones does not necessarily mean that immediate success will be achieved. The vessel becomes more difficult to operate and, moreover, general safety is not necessarily increased. Thus, certain regulations in relation to safety against fire may even have further endangered the stability of the vessel by adding weight to the superstructure. Should it be ascertained that the present orthodox life-saving craft are nothing more than a concession to routine, then general safety would greatly gain by their replacement by lighter and more efficient means.

CAPTAIN RICHARD S. MANDELKORN, U.S.N.

A NEW LOOK AT THE SCIENTIFIC MANPOWER PROBLEM

THE AUTHOR

graduated from the U.S. Naval Academy in 1932 and received the degree of M.S. in Naval Construction from Massachusetts Institute of Technology in 1937. His experience includes service on combatant staffs afloat, at naval shipyards, in the Bureau of Ships, and in the Armed Forces Special Weapons Project, in the fields of shipbuilding and ship repair, damage control, guided missiles, and atomic weapons design. Recently he was Director of Value Engineering when that activity was conceived and initiated in the Bureau of Ships, and subsequently Comptroller of the Bureau of Ships. He is presently stationed at the U.S. Naval Radiological Defense Laboratory, as Commanding Officer and Director.

THE CURRENT and prospective shortage of manpower in the fields of science and engineering has received a great deal of attention in the recent past. A considerable number of independent solutions to the problem have been advanced, and some of these are being tried out on an experimental basis. My admittedly cursory investigations since undertaking this study have led to one inescapable conclusion. The only general agreement by all concerned with this situation is: "We do have a problem." But so far as an intelligent, forceful, well directed, and coordinated business-like approach to, and continuing attack on the problem is concerned—well, it is nonexistent.

My new look, then, will be in the direction of a discussion of where we find ourselves today, and what should be done about it—in specifics, rather than generalities. It would be presumptuous to assume that any of the ideas to be discussed are truly novel—so many intelligent people have been considering the problem assiduously. However, it is hoped that some of the proposals, at least, will have sufficient obvious merit to warrant further discussion, and ultimately, implementation. The thoughts presented represent a studied effort to gather worthwhile ideas from scientist, educator, and businessman. Accordingly credit, or opprobrium, should not accrue to the author, he is merely a sounding board. One thing is clear—the future health of our country depends upon its continuing technological growth, and for this we must look to an increasing capacity in the sciences.

Assume for the moment that we here recognize the gravity and magnitude of the situation, and can consider objectively the several discrete approaches necessary to contribute to an over-all solution. The greatest single task facing us is to secure *general* recognition of the existence of this problem, and its importance to the welfare of the country, present and future. Unless and until the nation is made aware, the necessary support for the broad remedial measures required cannot be forthcoming. This is because, as will be evident later, no stratum of our economy, no level of our nation's culture, will remain unaffected by the steps to be taken. The modus operandi for generating this awareness and for engendering a favorable atmosphere will be discussed later.

With these somewhat general thoughts as a background, then, I would like to consider the over-all

problem of inadequate scientific manpower in two broad sections—the short-time, or interim corrective measures available, and the longer range, broad solution.

The immediate steps which can be taken divide themselves into two categories, first, better utilization of available recognized scientific manpower, and second, recognition and utilization of currently unused potential in this area.

The inclusion of "Better utilization of available recognized scientific manpower" would imply that we are not now managing our scientific endeavors with maximum efficiency. This is correct; we are not. Now, how can we utilize our scientists more effectively? Several avenues of effort suggest themselves. First, use scientific personnel for generative thinking, not mental drudgery. Give the scientist as much second line assistance as he needs and can productively absorb, in the form of adequate technical support personnel, both laboratory and clerical. I am talking about sub-professional personnel who can effectively carry out experimental work under direction, perform calculations, and assist in report writing. Be sure the scientist is not be-devilled by administrative procedures which do not fundamentally require his personal attention. Give to him all the mechanical assistance modern computer techniques can provide. Program-wise, protect him so far as possible from outside-directed, lengthy, non-productive studies, and conversely, see that he is not oppressed by the imposition of a profusion of priority, brush-fire projects which interferes seriously with important long range programs. I am sure that these thoughts are not entirely new. But the need for early action in these directions is urgent, and the possible pay-off is considerable. Accordingly, a re-survey of internal operations by scientific administrators is highly important, and it is difficult for one not to believe that much can be accomplished by such an effort.

Now let us consider the other aspect of this question—that of recognizing currently unused scientific potential. In the first place, there remains in the considerable body of retired professional personnel a capability not being completely utilized. Our economic pattern today in many instances places on the shelf men of keen insight and fine intelligence, with abundant energy and of great experience, solely because of the rigorous enforcement of artificial age limitations or physical handicaps. There is no reason why many of this type cannot continue to be used, either directly, or at least in specific consultation areas. Accordingly, it seems desirable to be sure that we make full use of presently available national listings of retired professional personnel. This would negate to some extent, one would hope, the present unhealthy preoccupation with youth now evidenced by some of the newer research organizations. Further, retired people with engineering training provide a reservoir of latent teaching talent which should be exploited.

While on this general subject, it may be worthwhile to note that there have been recent instances of the successful establishment of a research activity in a geographical area previously uninhabited by this particular species of scientific animal. The manpower attracted from the environs was apparently previously unengaged in research endeavors.

Next, when we consider the even more important question of the future, we run head-on into the crux of the problem—education, and more specifically, education for the sciences. No individual with whom this paper was discussed failed to recognize this, bring it up, and express himself upon the subject. A wide disparity of views was encountered, but each of those interviewed had one thing in common with all others: his arguments were vehement. The lesson is a clear one; this is an area where it is not easy to be objective, but it is essential that we make the endeavor.

There are many approaches, but let us see if we can resolve the problem into components which are susceptible of analysis. I believe we can agree that first the child must be motivated to desire education in the sciences, then he must be prepared for this education. If he is so motivated, and properly prepared, higher scientific education should be available to all worthy of it. With this dissection in mind, further analysis can proceed.

First, *motivation*. There are many forces operating today to inhibit the child's motivation for a scientific education. All are significant, but perhaps the foremost is that thinking is not the fashion in our culture today, and hard work is not held up as an example of how to succeed in our economy. Our educational system, at least in most primary and secondary schools, cannot be said to place a premium on or to encourage individual thinking, or even, in many instances, to allow it. Conformity, and the "easy way," are the norm. Of recent years, there have been sporadic attempts to recognize "gifted" children and to provide them the opportunity to move ahead, but these are experiments, and are by no means general. Again, how can a child conceive and cherish a burning desire for a life in science in a world where the commonly held concept of a scientist is either an absent-minded, impractical (and often improvident) theorist or a sort of demi-god? Fundamental to proper motivation then, is the promotion of general understanding that scientists are people. In the area of motivation and its nourishment, we need to promote the growth of understanding that thinking is not only a good thing, but can be fun, that hard work may be interesting and not inherently abhorrent, and that scientists are people—in a nutshell, that a scientific career is a desirable one.

There are some specific tools which can assist in motivating the child. An important one is the wide-

spread establishment of general science courses in the junior high school. Such courses, if properly led, can intrigue the pupil with the many fascinating avenues of scientific thought, can impart to him the desire to learn more about them. They can exploit his innate desire to tinker, experiment and build, and lay a sound foundation for future development. However, this approach demands dedicated science teachers, capable of inspiring their pupils.

Scientists in many fields can lend a hand here, and to students of high school age, by supporting and contributing their time to national science clubs. These clubs could be organized along the lines of the very successful 4-H clubs, and I suggest that we look to the pattern of promotion, establishment, and operation of the 4-H clubs for guidance in this field.

Let us not overlook the fact that our need is not only for qualified research scientists who are original thinkers, but also for a sufficient body of technological support people to complement them. The latter need not come from the relatively small group of "advanced" children.

Next in order is a discussion of preparation for a scientific education. Recognize that the majority of our public secondary schools today do not even offer all subjects pre-requisite to a scientific education in college. I refer to physics, chemistry, and mathematics beyond simple algebra. Thus, even the motivated child is thwarted, and others who might be inspired are left unenlightened. The first step, then, is to restore to the curriculum those subjects, essential parts of the pre-science preparation, which are vanishing like the American Indian. In order to implement this, a greater flow of qualified, dedicated teachers is essential, since presently science and mathematics teachers are in short supply.

The reason for this is two-fold—first, straight economics, and second, the relatively low position teachers occupy in our modern American culture. But—restore the prestige of the teacher, and pay him a decent living wage, and the supply will grow.

Of course, there are many other facets to this problem, such as the oft-repeated accusation that teachers are preoccupied with pedagogical methodology to the exclusion of interest in the subjects they are teaching, that teachers are so loaded with extra-curricular responsibilities involving PTA, coaching, health plans, savings plans, and the like that the encroachment upon their professional time is intolerable, that school boards are notoriously unsympathetic to educators, that citizens and taxpayers are not responsive to the dollar demands of a proper educational system, that education today places a premium on mediocrity, and so on, ad infinitum and ad nauseam.

One arrives at the conclusion that a powerful coordinated attack is needed on three fronts, and that failure in any one of these areas can vitiate the remainder of the effort.

First—parents—and, ergo the American public, must be made aware that a scientific career is a fine one to which their children can and should aspire, and that our educational system should be overhauled to suit this concept. They should be led to understand that the scientist's remuneration although not as high as we would wish, is not scanty, particularly for the young graduate. Second—the child—must be provided with motivation, and with the inspiration and opportunity to grow intellectually as fast and as far as his intelligence will permit. Third—the educators—must be brought to the realization that our educational system must provide inspiration for the average child, from whom technicians can develop, and full opportunity for the advanced child to exploit his talent. We need, also, to develop in teachers the desire for a career in teaching science and mathematics, today considered "difficult" subjects.

How to bring this about will be discussed shortly. But first we should consider the availability of scientific higher education for those qualified for it and desiring it. Today our colleges and universities cannot accommodate a considerable percentage of the qualified students desiring to pursue a scientific education. Inadequate facilities and lack of instructors, as well as increasing stringency of funds are the reasons given. Prominent educators tell us that fewer than 50% of the children who could profitably pursue a scientific carreer are now going into science, for one reason or another. It appears that two steps are necessary, assuming that by some means all of those with the necessary mental qualifications can be brought to matriculation. The institutions of higher education must grow, so that they will have adequate physical capacity and staffs to cover their prospective needs, and economic considerations must not prevent the qualified student from receiving a proper education.

Industry is recognizing these lacks, to a degree, by recent programs in assisting students through college and university, and direct grants-in-aid to the institutions. In addition to the well known cooperative educational program, some corporations are giving summer employment to high school students after two or three years of high school, and then grubstaking them through their higher education on a cooperative plan. This approach looks like a good one, worthy of wide extension. Time available has not permitted exploring many interesting and worthwhile avenues this study has opened up, but in extenuation I offer the thought that any single paper on this subject must be incomplete.

Nevertheless, there is at least one approach to the over-all problem of bringing all mentally qualified students to the point of entering upon a higher education in science with proper motivation and preparation. The major problem appears to be one of educating the public, and to this end, a strong, well directed, and properly-financed attack along proven

lines appears worthwhile. One would think that this could best be handled by a public relations organization versed in proper exploitation of the mass media, enlisting the cooperation on a non-profit basis across the board of the TV networks, the movie industry, and the press. Support of such an endeavor could possibly best come from a non-profit educational foundation, supported by private philanthropists, and by industry. Much is being done along these lines today, but since these programs are uncoordinated, their value is greatly diluted. It would appear that a strong, early effort along these lines is urgently needed.

As an example of the success of this mode of attack, many have cited the present stature of the medical profession in the eyes of the American public, and the fact that despite the rigours of a medical education, our youth continues to be attracted to it in great numbers. There is no reason why careers in science cannot be made equally attractive.

But this will not come about by conversation between scientists and educators, or lectures to women's clubs and PTA's. A directed, vigorous campaign aimed at destroying our national apathy—and by that I mean the attitude of the man in the street—is needed—and is needed now.

The purpose of this discussion has been to bring to general attention a view of the scientific manpower problem today and tomorrow, and some thoughts on how to go about improving the situation. It has been interesting and stimulating to prepare this study, because it has led to the conviction that our nation can and will, with proper direction, conquer the shortage of scientific manpower.

Ultrasonic test equipment can now be used to measure thicknesses and detect flaws in metals. Such equipment has been used for flaw detection in large steam turbine rotating shafts, compressor piston rods and large gas engine crankshafts. In October, 1956, Dr. Floyd A. Firestone was presented the Franklin Institute's Edward Longstreth Medal for the invention of the first practical ultrasonic test equipment for this purpose.

CAPT. CHARLES W. SHILLING, MC, USN (Ret.)

IS BRAIN POWER NEEDED IN A PUSH-BUTTON NAVY?

THE AUTHOR

is Deputy Director of the Division of Biology and Medicine of the U. S. Atomic Energy Commission, having recently retired from the Medical Corps of the U. S. Navy after twenty-eight years of service. During his time in the Navy, he spent fifteen years in research administration, nine of which was as Director of Naval Medical Research Laboratory in New London, Conn., and six of which was with the Office of Naval Research in Washington, assisting in the direction of a national research program.

THERE IS A LOT of talk about "push-button" war and a "push-button" Navy. By this I presume that most persons who use the term mean that many of the operations involved—navigation, fire control, and the general operation of the ship are now automatic—the man has been replaced by the machine. In the thinking of some people this means that the man is no longer needed, at least not in the numbers formerly required. Some even go so far as to suggest that men of lesser intelligence and inferior training can run the Navy when the machines have been perfected and installed.

It is true that we have advanced a long way in automation from the U.S.S. *Constitution* to the U.S.S. *Nautilus*—from sail to atomic power. But I believe I can prove to you that the requirement for trained human brain power has increased in proportion to the advance in automation. The paramount question actually is, is the human brain capable of handling the problems associated with automation, and can we find the required quantity of such brains to operate the complicated machines of the present technological world?

When one thinks of complicated machines, the computer, the so-called "giant brain," immediately comes to mind as the ultimate in complexity. There are many kinds of computers: the digital machines, the analog computers, and all of the possible variations required by special problems or tasks, down to the relatively simple and closely related servomechanisms.

The Navy has used servomechanisms in simple form from the days of sailing ships although, of course, they were not called by any such name for these new technological terms have been coined but recently. Actually the rudder on a sailing ship is a type of servomechanism—the helmsman turns the wheel which shortens the cable which in turn pulls the rudder to one side and the direction of movement of the ship through the water is changed by the force of the water against the rudder.

I well remember my first experience with the operation of the bow-planes of a submarine while running submerged. Before too long I had the submarine going like a porpoise. This is a good example of a servomechanism and feed-back system and the wide oscillations which occur if it is crudely constructed or ineptly operated—the latter being the case when I was on the bow-planes.

When the gyro compass is cut in on the steering circuit and the steering made automatic you have an analog computer at work. This will be made clear by the following definition: an analog computer is a machine which is capable of the usual arithmetic operations of addition, subtraction, multiplication, and division and in which a number is always represented, not by digits, but by such things as the linear or circular position of an object, or an amount of electrical voltage or current. From this definition it is apparent why so many types of analog computers are used aboard Navy ships, from the relatively simple automatic pilot to the much more complex control mechanism for the guided missile.

From the last statement it would appear that the analog computer is a recent development, but the truth of the matter is that every Midshipman since the founding of the U.S. Naval Academy has received his first instruction as a plebe and has personally owned, and I hope used, an analog computer—the slide rule! The slide rule was developed around the year 1600 and is a simple, yet very efficient analog computer. In the slide rule an analog is set up be-

tween distance along the scale and the logarithm of the number represented. Thus by adding distance we are in effect adding logarithms and so multiplying the number represented.

Analog computers are in general designed to solve ordinary differential equations. That is why they are so useful as system elements for fire control, as gun directors, for guidance computers and for data processing.

Two of the most complex of all are the analog computers, TYPHOON and RAYDAC (popularly called "Hurrican") which handle guided missiles in flight. It is difficult to imagine that a machine could be built that could handle all of the data necessary to control an object hurtling through space at such unbelievable speeds as those attained by the Navy's guided missiles *Regulus, Matador, Snark, Navaho, Terrier,* and the *Atlas.* Yet these computers are able to represent a guided missile in flight in *real time* to an accuracy and completeness which it is estimated could only be duplicated digitally if the present enormously fast digital computing machines were twenty times faster than they are now! Guided missiles would not be possible without the analog computer. In this connection it might be of interest to note that the Navy has developed over the last nine years a $55,000,000 establishment—the U.S. Naval Air Missile Test Center (NAMTC) at Point Mugu on the Pacific coast of southern California. Here they have the giant and complex RAYDAC computer. To maintain it in operation there is an organization, Computer Control, Inc., with 51 people aboard.

The Navy is always in the lead in all advances in weapons of warfare and, as pointed out by Lieutenant Commander Allan P. Slaff,* she, of course, has guided missiles ships, the guided missile cruisers *Boston* and *Canberra,* as well as many other types of ships capable of launching missiles.

Navy uses of analog computers are not limited to guided missiles or to shipboard systems. For example, REAC is an electromechanical machine used on problems dealing with the design of guidance and control systems, with stabilization, with the dynamics of the combustion process and with related problems in simulation. These are, of course, of primary interest to aircraft design engineers. However, at present, at least 75 REAC machines are in use at industrial and government laboratories, changed or adopted as necessary to make them more suitable for the problems of the local laboratory.

Almost all of the simulated or synthetic training in the Navy depends to a large degree on the use of analog computers. In describing the new dry-land submarine to be built at New London, Connecticut, the Navy says, "The trainer will simulate all characteristics of the newer submarines, even to handling in turns and "feel" of the various controls when the ship is in motion. When improperly ballasted or trimmed, the ersatz submarine will list or dive in a realistic fashion. An electronic computer receives the manipulations of the various controls inside the simulator as electronic signals and translates them into readings on the compass, gauges, and indicators inside the submarine." *

Ten years have passed since the first high-speed automatic digital computer, the ENIAC, startled the world with its 1,000 arithmetic operations per second. Since then at least 100 large-scale electronic digital computers have been completed in this country and in England. A digital computer may be defined as a machine which is capable of the usual arithmetic operations of addition, subtraction, multiplication, and division and in which a number is always represented by the integral digits of an appropriate number system. An automatic digital computer always possesses: input, memory, arithmetic unit and control, and output. Input into the machine may be by any of the following devices: switches which can be set; typewriter coupled to the computer; paper tape devices, mechanically read; paper tapes, photoelectrically read; and magnetic tapes and wires. These devices range in speed from 2 characters per second to 10,000 characters per second. Memory systems, essential for the operation of a digital computer range in storage capacity from a few hundred items (called bits) of information to many millions. Most modern machines keep basic instructions and numbers in a common memory pool holding from 10,000 to 1,000,000 bits. Auxiliary storage can bring this up to 20,000,000 bits of information. Arithmetic Unit and Control on most machines is constructed so as to allow instructions to be given for the following activities: addition; subtraction; division; multiplication; shift; read (i.e., bring in a number from the input medium); write; conditional transfer (i.e., take next instruction from one register if a certain number is negative and from some other register if the number is positive or zero); logical multiplication; and halt. The output is similar to the input and includes the following possibilities: modified typewriter, teletype punch, magnetic tape, high-speed printer, and photographic recording. Speed ranges from a few characters up to 10,000 characters per second. It is easy to see, with the vast possibilities inherent in such a machine, why some writers have confused its accomplishments with thinking.

To what use could the Navy put such giant machines? It would take a fair-sized tome to do justice to the answer to that question but let us mention just briefly some of the many problems on which the Navy has put the digital computers to work.

The Bureau of Ordnance in the Navy was a pioneer in the digital machine field and is jointly responsible with the Ordnance Department of the Army for the extensive array of machines now at the Ballistics Research Laboratory at Aberdeen and at the U.S. Naval Proving Ground at Dahlgren.

The David Taylor Model Basin has two UNIVACS in constant use for calculating design problems; each machine cost approximately $850,000 and the cost of

* Page 812, August 1956 Naval Institute Proceedings.

* O.N.R.Research Reviews, May, 1954.

running one machine for one year on a 24 hour basis is about $265,000. It may be of interest to note that the radical but highly efficient hull design of the new atomic-powered submarine, *Nautilus*, was calculated with the aid of these machines.

The Bureau of Ships now offers a new service by providing "analysis and machines for large-scale high-speed computation and data processing, in connection with problems in statistical, logistic, scientific, accounting, engineering, budgetary, and other information-handling fields."

The Chief of Naval Operations recommended and the Secretary of the Navy directed the Office of Naval Research to set up a logistics research group and from this grew the Logistics Research Project and the specially designed Logistics Computer which has been so successful in solving problems in logistics.

The Office of Naval Research supported much of the pioneering work in the development of computers. They realized early the need for simpler and cheaper machines and gave partial support to the development of the CALDIC at the University of California at Berkeley. Since this machine cost around $50,000 while others have been produced for as much as $4,000,000 cheapness is a relative term in considering the cost of digital computers.

In the scientific field, electronic digital computers have calculated the largest prime number, and they have worked out the design of the multi-element camera lenses. They have computed the inferences of theories concerning the growth of the universe and the natural relative abundance of the elements. They have calculated the design of transonic airfoils and the hyperfine structure of spectra of atoms. They are regularly involved in the calculation of numerical tables for aircraft and ship navigation by means of Loran. One was used to calculate pi (π) to over 2,000 places. In case you are interested, the 2,000th digit is zero!

We raised the question earlier as to whether the human brain is capable of handling the problems associated with these high-speed computers. It is true that the human brain is small in size when compared with these so-called "giant brains," but it is actually incomparably more giant than the computer in its versatility and capability.

In comparing the human brain with a computer it is well to bear in mind that the human brain envisioned all of the possibilities and actually developed these computers. One of the present commissioners of the Atomic Energy Commission, Dr. John von Neumann, who has had many honors bestowed upon him, recently received the $50,000 Enrico Fermi award in recognition of outstanding contributions to both the theory, and the design and construction of fast-computing machines.

Actually a digital computer as a brain is really quite stupid for it must be instructed in minute detail concerning every operation it is to perform. As it was expressed by one authority "A digital computer must be instructed in words of one microsyllable."

To prove that the human brain as a computer is really a vastly more efficient machine than any we have been discussing, let us look at some of the facts. This article is not the proper place to discuss the anatomy of this organ but it is of interest to note that it has been calculated that there are at least 10^{10} nerve cells arranged in complex and systemic three-dimensional patterns. The pulses and the activity between the cells are measured in one or two tenths of a millisecond. The cells can conduct as many as 200 pulses per second. In the terms of a machine, the brain is a logical machine in that each of these 10 billion relays has only two states—pulse or no pulse. There are integrating centers that control breathing, heart action, swallowing, and other automatic body functions. There are special areas for the control of special functions such as speech and writing, general sensory, and motor areas. Then there are higher centers dealing with intelligence, memory, judgment, and thought. All of this activity is accomplished by interlocking and inter-relating circuits. That there is ample scope for detail or fantasy in this mechanism is evident from the estimation that there are on the order of $10^{10,000}$ possible permutations. Suffice it to say that every bit of information available indicates that the human brain is the most superior computing machine we know.

In this connection, our friend, Warren McCulloch, in an article concerning the brain as a computing machine says: * "In a comparison of nerve cells and ordinary relays, the nerve cells are faster than electromagnetic devices, about as fast as thyratrons, about one thousandth as fast as vacuum tubes. However, they are so much smaller that, though their voltage-gradients are about the same in cathode to grid to plate, they take far less energy to operate. A large building could not house a vacuum tube computer with as many relays as a man has in his head, and it would take Niagara Falls to supply the power and Niagara River to cool it. ENIAC with some 10,000 tubes has no more relays than a flatworm. Moreover, nerve cells are cheap. If it cost a million dollars to beget a man, a nerve cell would not cost a mil, and until cathode, grid and plate can be printed on plastic with only monomolecular films between them, engineers cannot hope to compete with nature. Even then multiple grids would have to be worked out for gating the signals, because on big nerve cells what determines signal or no signal is special combinations from among as many as a thousand terminations of branches of tap roots of various nerve cells in the body of a single cell. At the present moment the most exciting parallel is in the configuration of electrodes on transistors. Computing machines designers would be glad to exchange their best relays for nerve cells. One reason for that is their long life since man gets no replacements from the day he is born until the day he dies. Every nerve cell in a man's head is

* McCulloch, Warren S., The Brain As a Computing Machine, Electrical Engineering, 492-496, June, 1949.

as old as he is, and most of them are still alive and working. Mechanically, they are more stable than other relays—and each keeps repairing itself."

With the replacement of tubes by transistors, the comparison is less favorable to the brain, for transistors take approximately one-millionth of the power of a vacuum tube and occupy a space about one-thousandth of the size. In addition, they produce virtually no heat, but even with these new devices, the brain is still infinitely superior in many ways, particularly in its enormous versatility.

In speaking of the relationship between men and machines, particularly the computing machines, Dr. Condon had the following to say: "Most of the machines which men have built hitherto have been ones which relieved his muscles of various back-breaking tasks, and in fact even made possible the performance of tasks which could in no way be possible with the use of human muscles as the prime motive power. Now we are standing on the threshold of an era in which machines can be built to relieve men of many routine and fatiguing mental tasks. I think these machines are destined to give to mankind a new dimension of freedom and power over the limitations of his material existence.

"At the same time, however, I wish to conclude on a note of warning against possible misconceptions. These machines do not think in the sense of having original creative impulses, nor artistic imagination, nor the capacity of aesthetic nor moral judgment. They are brains in the sense that they can do many routine things for which we use our minds, but they are not human in that they lack those higher qualities by which man is linked to the divine."

Since I believe that we have shown that the human brain occupies a position in our present day technology at least equal to, and in many cases far superior to computors, we must now turn to the question of whether we will continue to need high caliber brain power in the Navy and in what quantity this power will be needed.

In the first place we must have extremely high caliber brain power simply to run the machines, particularly the digital computers. Such statements as these appear in all of the literature on computers: "Quality of staff is of overriding importance, the annual outlay for an adequate staff may far outweigh that for the computer." ". . . digital machines, when fully exploited (and when and if the programmers and coders exist for their proper use) . . ." "Studies at Aberdeen and Dahlgren in operation of their computers showed that human error caused more trouble than machine error." "People of the greatest possible competence should be obtained for the staff. It is a fact that the real output of the machine will be very sensitive to the caliber of the staff, particularly to the analysts." But I think the best insight into the caliber of brain required to handle a computer efficiently is found in the analogy once made by John von Neumann, "Imagine that one has at his disposal one hundred human robots who cannot think but are able only to operate a desk computer and obey instruction faithfully. Suppose now that you give them enough instructions and data to keep them busy for a year, and that they communicate with you only by pushing a number under the door once a week. It is fairly easy to visualize the initial work and the care that must be given to the initial instructions to insure that the result of the year's work shall be meaningful. It is not so easy to visualize the situation which more nearly approximates the truth, namely that operating the fastest modern machines is equivalent to managing about a hundred of these groups simultaneously. It should be painfully clear at this point that the services of a great many exceedingly competent people are required for this purpose."

It is thus obvious that quality is necessary but how about quantity? Staff varies from one or two on the very small computers to a highly trained staff of upwards of a hundred on the large computers—specialists classified as analysts, programmers, coders, engineers, and technicians. The experience of the David Taylor Model Basin in operating their UNIVACs indicates that a staff of 40 people is necessary to efficiently operate one machine on a 24 hour basis—5 administrative, 15 operators, 6 engineers, 12 programmers, and 2 analysts.

But digital computers are only one item requiring additional intelligent and highly trained scientists and engineers. There is not the space, nor is this article the place to dwell upon the critical problem facing our nation of "The Growing Shortage of Scientists and Engineers" which was the topic of the sixth Thomas Alva Edison Foundation Institute held in November, 1955. Let us take time however, to quote three admirals who took part in the institute (one reserve, one retired and one active).

Rear Admiral Lewis L. Strauss said, "If there is to be another war among the great nations of the world before the human race discovers a method of abolishing recourse to combat, that war may be survived by the country with the greatest stockpile of nuclear weapons and instruments of their delivery. But such a war will almost certainly be lost by the country with the fewest resources in trained manpower . . . Deposits of uranium can be located, opened, mined, and converted into metal in a very short time. Appropriations can be voted quickly whenever the Congress decides them warranted. But men and women cannot be qualified in disciplines so exacting as modern science without a dedicatory period . . . and apprenticeship of years."

Rear Admiral Frederick Furth said, "Everyone who has considered the nation's scientific and technical manpower situation even casually now recognizes that shortages exist and that they will get worse . . .

"The problem has arisen because the American economy is based upon a steadily expanding technology, nourished by extensive scientific research and development. As new industries and new tech-

niques resulting from this scientific research and development are gradually built into the economy, more technically trained people are required merely to keep the wheels turning and the new economy in operation . . .

"Advances in military technology have greatly sharpened the need for large numbers of highly trained technicians in the armed forces . . . 'Guided missileman' and 'aviation fire-control technician' are typical of the new jobs in the Navy. Each has a training time of 25 months . . .

"We must provide for the education of the thousands of scientists and engineers required by our research and development effort, and we must nurture the growth of trained sub-professional workers to insure that we are not creating an industrial and military establishment so complex and sophisticated that we have forgotten to provide the people to operate and maintain it."

Rear Admiral Hyman Rickover said, "For the last eight years my work has been in the field of nuclear power. In dealing with the problems involved in developing this new source of energy, I have found them to be but one facet of a much larger problem—how to provide the trained men and women to maintain the momentum of our rapidly expanding technical civilization . . . What is certain is that unless the number of our scientists and engineers increases at an accelerated rate, our economy will be in serious trouble for lack of technological nourishment, because our pool of graduate engineers is the source from which arise nearly all our technological advances from jet engines and nylon, to earth satellites, atomic power, and intercontinental missiles.

"The United States, if it is to succeed in its role of world leadership, must produce citizens who have the wisdom, the vision, and the knowledge to grapple successfully with world problems; . . ."

And Vice President Nixon said, ". . . The world of tomorrow belongs to the nations that lead in scientific research and technical skill. We shall pay a great price if we fall behind in this contest."

In this field as in others, the Navy has led the way. We have the Naval Academy to train our own officers, we have an arrangement for increasing the number of officers through reserve officer training courses at the universities. We have various types of schools for advanced or graduate training for officers including the Naval War College. We send many of our officers to universities and technical institutes for advanced training. We have an almost infinite number of special schools to train our enlisted technicians.

But this is still not enough, for the Navy is the largest single user in the United States of scientists, engineers, technicians and trained manpower in general.

We should study carefully our educational and training role and make certain that our Navy schools are completely up-to-date and in tune with the technological advances; and then we should redouble our efforts to assist in the production of more and better trained scientists and engineers that are so desperately needed if the nation is to fulfill her destiny.

Character and leadership for which the Navy has always been famous will never be produced by electronic "brains."

TRANSAC (Transistorized Automatic Computer), a new high-speed, airborne, digital computer, which will consolidate the functions of many conventional airborne computers, has been developed. Possibly the first completely transistorized, expandable, control system, it can process a typical aircraft problem involving many hundred different instructions and solve it in 1/30 of a second.

"THE WELDING JOURNAL"

HEALTH ASPECTS OF WELDING

ACKNOWLEDGEMENT

This article is based on a paper presented at the National Spring Meeting of the American Welding Society in Buffalo, N. Y., May 7–11, 1956. The authors, Dr. B. L. Vosburg and J. J. Ferry, are associated with the General Electric Company. The article was published in the October 1956 edition of "The Welding Journal."

SIR HUMPHREY DAVY[1] in 1810 reported the successful welding together of various metals by means of heat generated with electricity. It was nearly a century later before the idea got a firm foothold in industry, and it required the impact of two world wars to make arc welding the undisputed process for joining metals.

POTENTIAL HAZARDS—THEIR EARLY RECOGNITION

During the 1920's and 1930's the application of this newly applied old method spread like wildfire and largely took the place of many slower, more laborious noisier methods. The more efficient process came to be used even for tank, bridge and ship construction, etc. It was during this rapid growth period that the wholesome suspicion about the welding process entailing health hazards became more than suspicion when sporadic illnesses and even deaths were reported by a number of observers. Invariably, one common denominator was found for the death cases. The welding had been done in relatively or severely confined spaces. In these death cases both the oxy-acetylene and the electric-arc process were implicated. In 1935 Drinker[2] and others investigated the exact cause of these fatalities. It was found that welding fumes conducted into an animal chamber caused animal death even when the fumes had been filtered. Autopsy of the animals showed that death was due to severe lung irritation and edema. Gas analysis gave high values of nitrogen oxides. It was also demonstrated that animals exposed to high concentrations of iron oxide were unaffected. However, it was later discovered that X-rays of fairly long-service welders commonly showed a seemingly harmless lung deposition of iron oxide that came to be known as welder's siderosis.

During the 1920's it was not uncommon for welders to suffer great inconvenience and discomfort from eye exposure to the welding arc. Gradually, however, when welders and their associates were afforded very adequate eye protection and instructed in its use, the incidence of so-called welders' eye became more and more a rarity.

Early welding had been done with a carbon arc or with bare-steel electrodes. The need for better welds of an increasingly greater variety of metals was met by the introduction of the coated electrode. This process[3] which shields the weld from oxidation had been developed in 1910 but only when a method of extruding the coating onto the rod was perfected in 1927 did it become economically feasible to use it. The extruded coatings[4] contained in varying and secret amounts, besides organic materials such as rags, many easily volatilized metals including manganese, phosphorus, vanadium, chromium and silicates. After much study it was determined that there was essentially no difference in the health hazards involved between bare and covered electrodes because the increased danger of more total fumes from the covered electrode was just about offset by the greater production of potentially dangerous oxides of nitrogen inherent in the bare electrode. Ventilation requirements and other protection remained about the same.

NEED FOR STANDARDS

Because of the occasional accidental deaths and because of the newness of the welding art, a great deal of apprehension naturally spread to the Departments of Health and Labor in various states; an apprehension that was shared by many investigators in the field of hygiene and toxicology and by indus-

trial physicians. Soon many of the industrialized states, through committee action, attempted to set up standards for the protection of the health of welders. The New Jersey Code [5] was one of the first to be given widespread publicity in 1940. Shortly after the American Welding Society, in collaboration with the American Standards Association, developed a National Standard [6] that serves as a source of recommended practices pertaining to health and safety in welding.

In 1942, at the request of the National Safety Council, Cranch, with Vosburgh's collaboration, presented a paper [7] at the 31st National Safety Congress at Chicago. Emphasis was given to the real welding hazards, including actinic radiation and air contamination by gases and fumes. What he had to say then is largely true today. The paper described the necessary precautions for eye protection and the need for adequate skin covering. Requirements for ventilation were set on the basis of making certain that the very irritating ozone and nitrogen oxide gases, whose threshold limits had not yet been well established, would be diluted to the point of safety for the welder. Probably the most important contribution of the Cranch and Vosburgh paper was in the emphasis that the very precautions and provisions needed for eliminating genuine hazards would automatically eliminate all of the fanciful or unreal hazards that had come to pervade the anxious minds of many investigators at that time. The authors personally quashed one fanciful rumor that X-rays from the welding arc would produce sterilization in male welders by having some of our welders carry X-ray films in their pants' pockets.

During World War II, Professor Philip Drinker of the Harvard School of Public Health, had responsibility for the health of welders in the shipbuilding industry. By the application of common sense, but more particularly by the application of good local exhaust ventilation, it was discovered that arc welding could be made a safe operation even in the holds of ships.

LOW-HYDROGEN METHOD

Chiefly since World War II, many new and unique methods have been perfected for minimizing oxidation in the weld; also for easier welding of steel and non-ferrous metals. One of the first of these new methods involved a low-hydrogen coating. This was accomplished by the use of an electrode coating containing fluorides, a material not customarily present in the coatings of mild-steel electrodes.

The fumes produced by electrodes bearing fluorides contain solid particles of fluoride salts, the concentration depending upon the amount and type of fluoride in the flux, the rod size and the amperage used. Under some conditions, gaseous fluorine compounds, probably hydrogen fluoride, may be produced, but normally in extremely small amounts.

Exposure to excessive concentrations of fumes containing fluorides will produce nose and throat irritation, and chronic nosebleed has been reported. Frequently, a tolerance to the irritation may develop, but a cessation of complaints does not necessarily mean that conditions are safe. Absorption of excessive amounts of fluorine compounds through the lungs may produce fluorosis (a change in bone structure) or other systemic effects. The generally accepted maximum allowable concentration [8] of fluorine as fluorides is 2.5 mg per cubic meter of air; for hydrogen fluoride, three parts per million.

The fluxes used in welding stainless steel, nickel and aluminum usually contain fluorides. The same general comments as for low-hydrogen covered electrodes will apply.

Tests have shown that the fumes from stainless-steel electrodes may also contain approximately six per cent of chromates, calculated as CrO_3, apparently produced by oxidation of the chromium. When concentrations of soluble chromates exceed the maximum allowable concentration of 0.1 mg of CrO_3 per cubic meter of air, inhalation of such chromates will produce irritation of the upper respiratory tract.

SUBMERGED-ARC WELDING

In submerged-arc welding, the arc is covered with a rather heavy layer of granulated flux which normally shields the arc. These fluxes also contain fluorides. Tests have shown that, when the flux is heated to the melting point, hydrogen fluoride (hydro-fluoric acid) or other gaseous fluorine compounds are produced. The amount of hydrogen fluoride produced depends on the amount of flux heated and the temperature reached. In our experience little difficulty has been noted during machine welding where the size and position of the arc is carefully controlled. There have been complaints of nose and throat irritation during manual welding particularly where large amounts of metal were being deposited.

THE INERT-GAS METAL-ARC PROCESS

In the further interest of improving welds and extending the application of welding, the inert-gas metal-arc welding process has been developed. In this process, oxygen is kept away from the welding arc by means of a mantel of inert gas, originally helium or argon, and more recently the less inert carbon dioxide. This process has introduced some very new and unusual potential hazards. The ultraviolet radiation is increased approximately tenfold, depending on the current density, the type of metal being welded and the particular inert gas used. This calls for additional precautions,[9] both in protecting the skin and eyes of the welder and in shielding nearby personnel. Dark—preferably wool—clothing must be worn to cover *all* exposed skin surfaces. Tests by several authorities have shown that adequate eye protection from the ultraviolet is given in the use of the welding lenses that are recommended for the various amperages of ordinary arc welding. The increased brightness from visible light, however, may make it necessary for some people to use lenses

that are one or two shades darker in order to prevent eye strain and depletion of the visual purple which is the cause of snow blindness during the summer months in the arctic region. It is worthy of note that intense ultraviolet light may cause the disintegration of cotton clothing. Ozone, which may be hazardous, of course, in any type of welding under conditions of inadequate ventilation, is produced in larger amounts by the inert-gas metal-arc welding process. The amount produced will vary with the type of metal and gas used; also with the current density and the atmospheric humidity. Industrial hygienists have had a bit of a dilemma here because the recently established threshold limit of ozone[10] of 0.1 ppm is quite commonly exceeded. However, even though respiratory irritation has been reported, serious illness has not been encountered, probably due to the fact that the welding arc time is intermittent and usually less than fifty per cent of the working day. It has also been shown experimentally[11] that minor lung exposures to ozone afford additional protection against more serious exposures. Obviously this potential hazard must be given due consideration (see Table 1).

TABLE 1—*Ozone and Nitrogen Oxides*

Gas used	Amperage	Ozone, ppm	Nitrogen oxides, ppm
Argon	55	0.1	...
Helium	55	0.1	...
Argon	110	0.5	...
Argon	110	0.6*	...
Helium	110	0.1	...
Helium	110	0.1*	...
Helium	110	0.0*	0.3*
Argon	110	0.4	2.5
Argon	110	0.6	3.0*
Helium	110	...	0.5*
Helium	110	...	0.3
Argon	110	...	3.0*
Argon	110	...	2.5

* Normal rate of gas flow was doubled.

TABLE 2—*Phosgene*

Gas used	Trichloroethylene, ppm	Phosgene produced, ppm
Argon	0–15	45
Argon	60	140
Argon	100	180
Argon	140	280
Helium	30	6
Helium	30	4

Still another potential hazard in the inert-gas metal-arc welding process relates to the ready conversion of certain chlorinated hydrocarbons to phosgene under the intense actinic radiation (see Table 2). For example, trichloroethylene, commonly used in degreasing operations, may give rise to a dangerous concentration of phosgene[12] even when the concentration of the trichloroethylene vapors is too low to be detected by the sense of smell. Thus degreasing and inert-gas metal-arc welding jobs must be separated physically. It may suffice to accomplish this isolation by ensuring that a positive air current passes from the welding area toward the degreaser.

Because the inert-gas metal-arc welding process produces high temperature, larger amounts of metal fumes may be encountered—again the amount depending chiefly on the current values and the type of metal used. These high concentrations of metal fumes will commonly demand local exhaust ventilation of a type that does not disturb the inert-gas mantel. It is noteworthy that a number of welders have become ill when exposed to copper fumes. The nature of the illness is probably a copper metal fume fever.

While welding nickel using this same process in a poorly ventilated area two welders and their helpers became ill—one welder and one helper seriously ill, with acute pneumonitis.[13] With the installation of enclosed booths, properly exhausted, no further untoward effects were noted.

There has been considerable anxiety, originating with theoretical physicists, in the use of thoriated tungsten electrodes in the inert-gas metal-arc welding process. One company stopped the use and the manufacture of these electrodes for a period because the data set forth by physicists indicated the likelihood that thoria, having low-grade radioactive properties, might present a long term danger. The best published information,[14] however, at this time indicates that there is no hazard from the inhalation of thoria particles except possibly if the welding is done in a confined space. The added precaution should be taken in dressing a thoria-tungsten electrode on a grinding wheel to ensure that it is sufficiently well ventilated to remove all of the dust produced or else keep the tip of the electrode under water during the dressing.

When carbon dioxide is used as a shielding gas, some of it is decomposed by the arc to form carbon monoxide, the amount dependent upon the arc temperature. This potential hazard should also be entertained.

THE ATOMIC-HYDROGEN PROCESS

The atomic-hydrogen arc-welding process was developed by Langmuir[15] in 1926. In this process, hydrogen is passed through an arc drawn between two tungsten electrodes. The hydrogen, by disassociation and reassociation, greatly increases the amount of heat available, and also serves to blanket or shield the weld from the air. Filler metal, where needed, is fed into the arc separately. The hazards associated with this process are very similar to those described under Inert-Gas Metal-Arc Welding.

CARBON-ARC WELDING

In this old process, a carbon electrode is used with filler metal being added separately if required. When a shield, either gas or flux, is used, the hazards become similar to those under Inert-Gas Metal-Arc Welding.

ARC-WELDING ALLIED PROCESSES

We have devoted considerable time to some of the newer welding methods in order to better pinpoint their inherent potential hazards. A discussion of the health aspects of some of welding's allied processes will help complete the picture.

Cutting

Gas welding and oxygen cutting on mild steel do not generally produce fumes which are harmful under normal conditions. Some oxides of nitrogen may be produced, but these are of no concern except in confined areas.

Powder washing is a form of cutting in which iron powder is fed into the flame. The fumes produced contain, principally, iron oxide and are not considered harmful under normal conditions. However, the amount of fumes and dust produced is usually much greater than in straight cutting, and complaints of a nuisance condition may arise.

Brazing

Fluxes containing fluorides are frequently used in welding and in brazing brass, aluminum or other alloys. In this case the heat of the flame may produce hydrogen fluoride. The concentration of hydrogen fluoride in the fumes is frequently high enough to be irritating, indicating that it is over the maximum allowable concentration (3 ppm). The concentration produced in the general room air will depend on the room size, general ventilation and the amount of welding or brazing being done. If the flux penetrates the outer skin surface through nicks or cuts, or around the fingernails, it may produce severe irritation. Skin contact should be avoided.

Some brazing alloys may contain cadmium which is readily volatilized on heating. The brown cadmium fumes so evolved are extremely dangerous, producing severe and even fatal lung damage on short exposure. The maximum allowable concentration for cadmium [16] is 0.1 mg. per cubic meter of air.

EXTRANEOUS HAZARDS

In the 1930's Alice Hamilton,[17] in discussing the various illnesses common to the welding trade, admonished:

"If the welder is using his torch on mercury-smeared metal he may get mercurialism; if on a tank that has held grease or oil, acrolein poisoning; if he is welding galvanized (which means zinc-coated) iron, he may have brass founder's ague; if he is helping to scrap battleships by cutting through steel sheets which were painted with red lead, he will surely have lead poisoning; . . . etc."

Welding on materials containing beryllium may produce an extremely dangerous condition. No such welding should be undertaken without proper clearance and then only after complete control of fumes has been provided.

Welding on tanks, pipelines or containers of any sort from which the contents have not been thoroughly removed may introduce a serious hazard by volatization or decomposition of the residue. This is particularly true where chlorinated hydrocarbons or plating solutions may be involved.

Since the possible harmful effects from welding, cutting and brazing operations are closely related to the fumes and gases produced, appropriate consideration must be given the matter of controlling the inhalation of such gases and fumes. For this purpose the AWS-Z49 [18] specifications of ventilation are recommended.

SPECIAL RESPIRATORY PROTECTION

When standard ventilation requirements cannot be instituted, for some reason, respiratory protective equipment may be required. Air-line respiratory or hose masks will give adequate protection from welding fumes. Air-supplied welding helmets are available commercially but have been used very little in industry because of the annoyance and discomfort involved. Respirators approved for metal fumes will give protection against metal fumes not more toxic than lead provided they are selected, used and maintained properly. Their general use is not recommended, however, because of the difficulty of being sure these provisions are carried out. No cartridge or filter respirator will give protection against oxides of nitrogen; an air-line respirator, hose mask or gas mask is required. Respiratory protective equipment is seldom required at welding operations. In those few instances where it is required, its use should be mandatory.

SUMMARY OF SPECIFIC PRECAUTIONS

The authors would like now to summarize some of the precautions that should be observed:

1. When welding in a confined space, local exhaust ventilation which is adequate to control fumes should be applied. Where any question of adequacy exists, an air-line respirator or hose mask should be worn.
2. When welding indoors on materials containing or coated with toxic substances such as lead, cadmium, etc., local exhaust ventilation should be applied. Air-line respirators are usually required whether such welding is done indoors or outdoors.
3. Fixed welding locations used for welding on stainless steels, nickel, aluminum or other materials where fluoride fluxes are used should be provided with local exhaust ventilation.
4. Local exhaust ventilation should be provided when nickel or copper is being welded by the inert arc process using the consumable electrode, or by the non-consumable electrode with amperages over 300.
5. All skin surfaces should be covered during inert-arc, carbon-arc or atomic-hydrogen welding.
6. Used tanks or other containers should be thoroughly cleaned before any welding is attempted. The explosion and fire hazard is considered by many to be the worst hazard of all.

A treatise on health in reference to welding would not be complete without brief mention of possible

negligence actions. If an employer fails to provide safe working conditions, the injured employee is entitled to workman's compensation under the state's statutes. If the manufacturer of the equipment used can be proved negligent in the design of equipment or in giving adequate warnings, recovery through common law courts may be permissible in some states. For their own protection, therefore, many makers of welding equipment point out the potential dangers and prescribe the safeguards to be taken. This added precaution on the part of manufacturers is apt to have a salutory effect upon the users of welding equipment. To illustrate, one manufacturer has admonished users of inert-gas metal-arc welding equipment with the following operating safety precautions:

1. Provide adequate ventilation.
2. Beware of degreasers.
3. Eye protection.
4. Protect the skin—operator should be protected.

HEALTH MAINTENANCE PROGRAM

Some employers have instituted health maintenance programs for welders. That preventive medical service usually consists of a good physical examination supplemented by a urinalysis, tests of vision and hearing and a chest X-ray. The examination is conducted about once a year and serves to spot siderosis or other lung pathology and any change in vision or hearing. The importance of good vision can be readily appreciated since it has a direct bearing on quality of work and the welder's ability to keep his helmet away from maximum fume and gas production. The examination may also demonstrate management's interest in the health of employees.

Like many other potentially hazardous processes, welding, in its many and varied applications, requires the cooperation of all the people involved in order to accomplish an optimum health status for the trade. Those who design and build and install the equipment have a big responsibility for the welder's health and so do the safety supervisor, the ventilating engineer and the industrial hygienist. But the welder himself must also share in good measure the safeguarding of his own health. An important part in learning his trade is the acquisition of a wholesome respect for the potential hazards involved. Unless a welder understands exactly why each and every safeguard has been afforded him, he is not apt to take his own protection seriously. Unless he really appreciates that the gases and fumes may be harmful, he will fail to develop the good habits of viewing his work from the side and away from maximum gas and fume production.

Adequate time spent in orienting and teaching the man who does the work will surely prove a good long term investment.

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"THE JOURNAL OF THE INSTITUTE OF METALS"

THE HISTORY OF MAGNESIUM

ACKNOWLEDGEMENT

This article is the Presidential Address, slightly abridged, delivered at the Annual General Meeting of the Institute of Metals, in London, on April 11, 1956. The author is Major C. J. P. Ball, Chairman of Magnesium Elektron, Ltd. The article was published in the July 1956 issue of "The Journal of the Institute of Metals."

INTRODUCTION

ALMOST 150 YEARS have passed since magnesium was first discovered, and this period can be roughly divided into three phases, 80 years of laboratory work, 40 years semi-technical development, and 30 years commercial exploitation. Outstanding dates in these periods are:

1808. Discovery.
1886. First commercial production from carnallite.
1923–26. Discovery of refining fluxes, of the important influence of manganese on the metal, and the first commercial extraction of the metal from anhydrous magnesium chloride.
1939, March. First metal extracted from sea-water in U.K.
1946. Successful rolling at high speeds of magnesium alloy ingot on steel mills in U.S. and U.K.
1946. Commercial production of magnesium-zirconium alloys.
1953. The start of the Dow Chemical Co.'s rolling mill at Madison, Illinois, U.S.A.

This story of magnesium and its alloys describes first the methods of extraction operated in the several producing countries, then the processes of alloying and fabrication, and ends with a brief commentary upon successful applications of the metal and potential development of the future.

The United Kingdom, in 1864, was the first country in Europe to produce magnesium in small quantity for photographic purposes.

Germany, in 1886, began to produce magnesium commercially on an industrial scale, and to develop alloys for use as engineering materials. The results of the German work, supported by that of the U.K., France, and Italy, gave Europe the lead for some years in the production and usage of the metal for engineering purposes. Between the years 1929 and 1938, in addition to aircraft and military applications, a fairly wide range of products for civilian usage became firmly established.

From about 1939 onwards, the Dow Chemical Company of America, which started experimental extraction of the metal in 1916, began steadily to increase production of magnesuim and its alloys, and the efforts of that Company, stimulated by the great demand of World War II, enabled the U.S. rapidly to become the leading producer and consumer in the world—a position which she still holds today.

Published statistics for 1938 record the world annual production of magnesium as follows:

	tons
Germany	about 20,000
England	about 5,000
U.S.A.	about 2,500
France	about 2,500
Japan	about 1,000
Switzerland	about 500
Russia	about 500

The enormous increase in demand for magnesuim metal for war purposes, already visible in Germany, was met by rapid expansion of production facilities in the U.K., and still greater and more rapid expansion in the U.S.A. The approximate total quantity of magnesium produced by all countries for the period March 1939–40 was 32,000 tons; the comparable figure for the period 1943–44 was 228,000 tons, more

than seven times that of 1939–40. Unfortunately, the valuable properties of the metal were so little known that such tonnages could not be absorbed for civilian purposes, and so the fall in post-war production was even sharper than the war-time rises in consumption. By 1946, world production of pure metal was back to 10,000 tons per annum. World production in 1955 was approximately 124,000 tons, made up as follows:

	long tons
U.S.A.	55 000
Russia	50,000
Canada	8 000
Norway	7,000
U.K.	1,500
France	1,200
Italy	1,200

Magnesium is the eighth most abundant element and the sixth most abundant metal in the earth's crust, where it is present to the extent of 2.2%. Sea-water contains 0.13% magnesium metal, so that one cubic mile of sea-water represents 5¼ million tons of metal.

Despite the availability of the magnesium-bearing minerals shown in Table I, of which dolomite is the most abundant, by far the largest tonnage of magnesium is today extracted from sea-water by the Dow Chemical Company at Freeport, Texas, and by the Norsk Hydro-Elektrisk Kvoelstofaktieselskab at Heroya, Norway.

TABLE I—*Principal Minerals Available for the Production of Magnesium*

Name	Chemical Constitution
Magnesite	$MgCO_3$
Dolomite	$MgCO_3.CaCO_3$
Hydromagnesite	$MgCO_3.Mg(OH)_2.3H_2O$
Brucite	$MgO.H_2O$
Carnallite	$MgCl_2.KCl.6H_2O$
Kieserite	$MgSO_4.H_2O$
Kainite	$MgSO_4.KCl.3H_2O$
Serpentine	$3MgO.2SiO_2.2H_2O$

Magnesium is silvery-white in color, with a specific gravity of 1.74, i.e., rather less than two-thirds that of aluminum, one-quarter that of iron and steel, and one-fifth that of nickel. Its physical properties are shown in Table II.

HISTORICAL

Metallic magnesium was first isolated in 1808 by Sir Humphrey Davy, who, acting upon a suggestion made by Berselius and Pontin, was able to produce an amalgam of magnesium, and so obtained the metal by distilling off the mercury. During the next 50 years, the French chemist Bussy, the German chemists Liebig and Bunsen, and the French scientists St. Claire Deville and Caron all worked on the problem

TABLE II—*Physical Properties of Magnesium*

Atomic weight	24.32
Crystal Structure	Close-packed hexagonal, a = 3.2030 A., c = 5,2002 A.
Specific gravity at 20° C.	1.738
Melting point	650° C.
Latent heat of fusion	85.6 cal./g.
Latent heat of vaporization	1315 cal./g.
Mean specific heat (0°–100°C.)	0.25 cal./g.
Coefficient of linear expansion (20°–100° C.)	26.1×10^{-6}/°C.
Thermal conductivity (0° C.)	0.376 cal./cm.²/sec./cm./°C.
Electrical conductivity (0° C.)	24.47×10^4mhos/cm./cm.²
Electrical conductivity (100° C.)	17.50×10^4 mhos/cm./cm.²
Electrical resistivity (20° C.)	4.4611 microhms/cm./cm.²
Vapor pressure (650° C.)	2.28 mm. Hg
Thermal neutron absorption cross section	0.059 ± 0.004 barns/atom
Electropositive to most metals	

of producing metallic magnesium by various methods of reducing anyhdrous magnesium chloride. To Bunsen goes the credit of first recognizing the vital need to have a completely anhydrous electrolyte, and to Faraday that of first producing metallic magnesium by electrolysis of a fused magnesium salt.

Germany

In 1882, the German scientists Graetzel and Fischer investigated the use of carnallite from the Stassfurt deposits as a raw material for the thermal electrolytic production of magnesium. About 1896, Oettel discovered the harmful effect of water and other impurities, such as sulphur and iron, on the electrolyte, and the pioneer work of these scientists established basic rules for the start of extraction of magnesium on an industrial scale by thermal electrolysis from carnallite.

In 1886, the Aluminium-und-Magnesium-Fabrik, Hemelingen (Germany), designed and erected a plant for the dehydration and electrolysis of molten carnallite, $MgCl_2.KCl.6H_2O$, in cells incorporating Bunsen's original theory and design.

The Hemelingen process was later taken over by the Chemische Fabrik Griesheim-Elektron and transferred to its Bitterfeld works. Griesheim-Elektron later became one of the I.G. Farbenindustrie's group of chemical manufacturers.

The leader in this development was Gustav Pistor, under whose dynamic and far-sighted leadership the complicated problems of extraction of magnesium metal on an industrial scale were solved, and useful alloys developed and sold at prices which permitted their use as engineering materials.

For many years Pistor, ably supported by Moschel and his staff, worked on the problems of extraction of the metal from carnallite, but he found it impos-

sible to avoid the detrimental effects of hydroxyl groups, probably as components of basic salts, which, when electrolyzed, cause accelerated wear of anodes, with considerable losses in efficiencies. This led Pistor and his men to attempt the production of a truly anhydrous magnesium chloride. An added spur to their efforts was the fact that such a process would absorb some of the surplus chlorine from their increasing production of caustic soda. The decision of Moschel in 1924–25 to chlorinate the oxide at temperatures above the melting point of magnesium chloride successfully established a process for the chlorination of calcined and raw magnesite with carbon and chlorine, to give a completely anhydrous product, in accordance with the following known reactions:

$$MgO+C+Cl_2 \rightarrow MgCl_2+CO,$$

and $$2MgO+C+2Cl_2 \rightarrow 2MgCl_2+CO_2$$

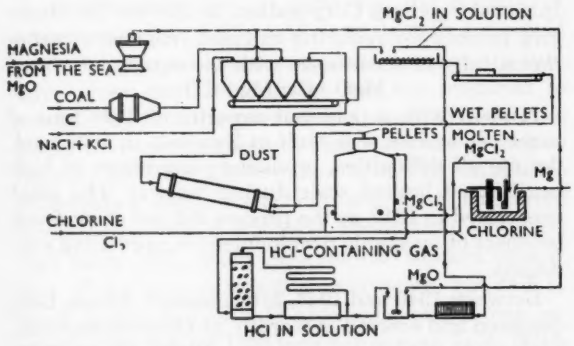

Figure 1. The I.G. Electrolytic Process used for the production of magnesium by Magnesium Elektron, Ltd.

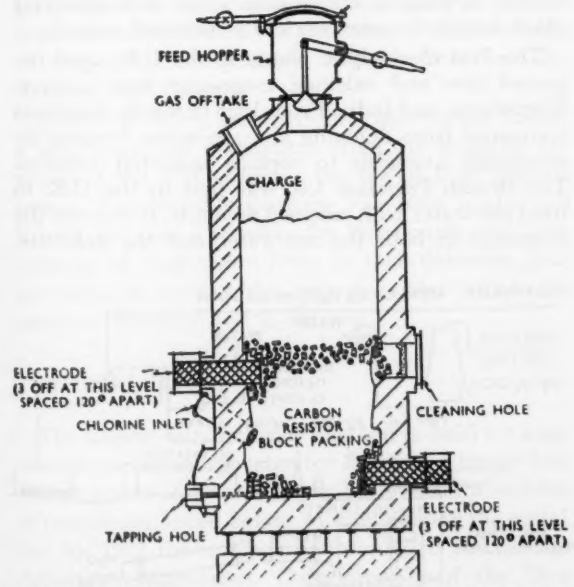

Figure 2. Sectional view of a chlorinator used in the I.G. Electrolytic process.

This process, shown in Figures 1 and 2, was responsible for a very large production of magnesium metal, not only in Germany but also in France, the U.K., the U.S., Russia, and Japan.

It is to the great credit of Pistor, Moschel, and their collaborators, that they overcame the many and great problems involved in the design, construction, and operation of plant for the production of anhydrous magnesium chloride, and the thermal electrolysis of the chloride, and so gave to the world a method of extraction which, on level terms, has proved itself competitive with any process yet known.

Details of this pioneer work, which led to the design and construction of the now standard equipment used in their electrolytic process, has been fully described by the late Dr. W. Moschel.[1]

To avoid importing magnesite into Germany, a process was developed in 1937 to treat local calcined dolomite with $MgCl_2$ solutions available as by-products from the potash industry. A large plant was erected at Teutschenthal to provide by this process the magnesia requirements of the expanded metal plants, the reaction being:

$$Ca(OH)_2MgO+MgCl_2aq. \rightarrow CaCl_2aq.+2MgO+H_2O$$

The German production between 1940 and 1945 by this process reached 28,000 tons of magnesium annually.

The Wintershall A.G., having found an improved and more economic method of extracting magnesium by the electrolysis of carnallite, erected a plant with an annual capacity of 6000 tons, making the total German production 34,000 tons per annum.

Pistor and his staff also sought a way of reducing magnesium by a thermal process directly from dolomite. The reaction between calcined dolomite and silicon takes place in accordance with the equation:

$$2MgO.2CaO+Si \rightarrow 2CaOSiO_2+2Mg$$

the calcium oxide contained in the dolomite reacting with the resultant silica to form calcium orthosilicate. After many experiments, they finally decided that a rocking resistor furnace with internal electrical heating to give a temperature up to 1400° C. under vacuum was the best type of furnace to use, and that ferro-silicon was the most practical reducing agent, the metal being condensed as a solid and subsequently discharged from the condenser in molten form. Furnaces were designed and built capable of giving a daily output of one ton of magnesium.

In 1939 some furnaces of this type were built for the Italian Government and installed at Aosta, where they operated during the war.

With the end of the war, all the German plants ceased production, and most have been dismantled. However, the Knapsack-Griesheim A.G., of the Farbwerke Hoechst Group, are now developing a new process for the thermal reduction from dolomite and hope to succeed with a new type of ferro-silicon reduction unit.

Production of magnesium from the magnesium chloride residues of the potash industry by thermal

electrolysis is again under review, the supply of by-product chlorine from the electrolysis being an added attraction in these days of demand for chlorine.

It is understood that the Vereinigte Aluminium Werke are also developing a thermal process for extraction from dolomite by a new type of ferro-silicon reduction unit which is operating successfully at the pilot-plant stage.

The United Kingdom

In 1859, the rapid growth of photography called for artificial light of high actinic value, and Bunsen and Roscoe read a paper to the Royal Society[2] recommending for this purpose the special properties of the light from burning magnesium.

Edward Sonstadt, an English chemist, became interested, and in 1862–63 he patented a process for reducing $MgCl_2$ by sodium and then distilling the crude magnesium in a current of hydrogen. In 1864, Sonstadt formed the Magnesium Metal Co. Ltd., at Salford, to make magnesium metal and wire, and Johnson, Matthey and Co., Ltd., sold 1400 oz. in 1864 and 7000 in 1865 at 25*s.* per oz. The works closed in 1890 because the product could not compete with German imports, at a price of 1*s.* 6*d.* per lb.

In 1914, Johnson, Matthey and Co., Ltd., and Vickers, Ltd., jointly put up a plant at East Greenwich, which, using the Magnesium Metal Company's process, made all the magnesium powder, wire, and ribbon required for pyrotechnics by the Allies. This works was closed in 1919, and production of metallic magnesium in the U.K. again ceased for nearly 20 years. During this period various processes were tried unsuccessfully, but it was not until 1936 that metallic magnesium was again made in the U.K.

Between 1920 and 1936, a demand for the metal for alloying with aluminum and for industrial and military use had been slowly built up by F. A. Hughes and Co., Ltd., and British Maxium, Ltd., later Magnesium Castings and Products, Ltd., based on imports from Germany and the U.S., respectively.

In 1935 F. A. Hughes negotiated an agreement to acquire for the British Commonwealth the patents of the I.G. covering Pistor's process for thermal electrolytic extraction, and formed Magnesium Elektron, Ltd., as the operating company, in which I.G. and Imperial Chemical Industries, Ltd., were the other shareholders.

In 1936 a works was erected at Clifton Junction, Manchester, which was designed to extract 1500 tons of magnesium metal per annum from imported raw and calcined magnesite by the electrolytic process, which began production in December, 1936. At Government cost, an additional 2500 tons per annum capacity was added, which started up in January, 1938. In 1940 a further unit of 5000 tons per annum was erected, which came into production in March, 1941. In 1942, the Government instructed M.E.L. to erect a further 10,000 tons per annum plant near Burnley, which started up in 1943.

In 1935–36, Murex, Ltd., built at Rainham a plant to produce 1000 tons per annum of magnesium by a thermal reduction process, using calcium carbide as the reducing agent. In 1940, this Company built at Government cost, a plant at Moss End, Lanark, to produce 5000 tons per annum, an output which it attained in 1942. Costs of production were high and, as there were also site difficulties, the plant was shut down before the war ended.

In 1940, the Lancashire Metals Subliming Corporation tried to extract under vacuum magnesium from both calcined magnesite and calcined dolomite, using ferro-silicon, by means of a high-frequency induction furnace working at 500 kc./s. Substantial quantities of metallic magnesium were recovered in a large pilot plant, but the efficiencies and overall economies were not sufficiently attractive to warrant construction of a commercial plant.

The Magnesium Metal Corporation was formed in 1938 by The British Aluminium Co., Ltd., and The Imperial Smelting Corporation, to operate the Hansgirg patents for reducing calcined magnesite carbothermically in accordance with the equation:

$$MgO + C \rightleftarrows Mg + CO$$

A plant with a potential capacity of 1000 tons of ingot per annum was built at Swansea in 1939, and, despite all difficulties, produced magnesium of high purity on a limited scale during the war. The plant was closed in 1945, as the process did not show much prospect of economic development in prevailing conditions.

Between 1940 and 1943, International Alloys, Ltd., designed and erected at Cardiff, at Government cost, a plant to operate a continuous thermal reduction process from calcined magnesite, using aluminum and ferro-silicon, intended to produce 5000 tons per annum. Owing to major difficulties in engineering plant design, it never worked at planned capacity.

The first electrolytic plants in the U.K. used imported raw and calcined magnesite from Greece, Yugoslavia, and India. From 1938 onwards, magnesia recovered from dolomite and sea-water became increasingly available to replace imported supplies. The British Periclase Co. was first in the U.K. to treat sea-water with calcined dolomite, to recover the magnesia in both the sea-water and the dolomite.

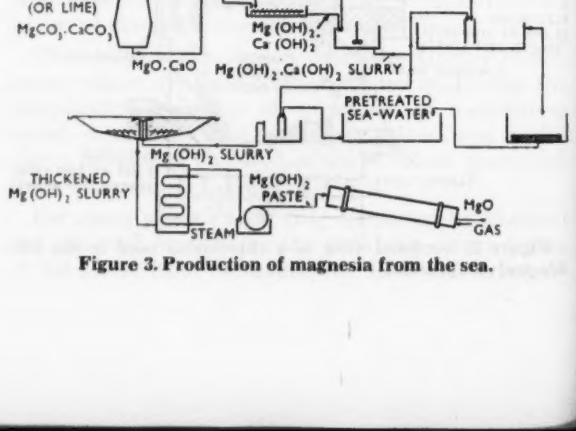

Figure 3. Production of magnesia from the sea.

The process is outlined in Fig. 3. The magnesia obtained by this process was of a highly reactive caustic type, well suited for chlorination to anhydrous magnesium chloride, and 40,000 tons per annum were produced during the war years. In March 1939, M.E.L. first used magnesia from the British Periclase Co., and the metallic magnesium then extracted was the first recorded commercial production from sea-water.

After the war, the U.K. plants were successively closed until, by 1947, there was no longer any production in the country. Those operating thermal production processes were dismantled, and the electrolytic plants put on "care and maintenance."

Ignoring the accumulated war stocks of magnesium in the U.K., production of the metal could not have been continued without Government support because conditions had changed. The increase in cost of electric power was so great that the electrolytic process, which in 1939 could compete with any world producer, was no longer competitive without a subsidy, which the Government was not prepared to provide. By 1951 the position had again changed; the stocks of pure magnesium had been used, and in January 1951 the Government instructed M.E.L. to re-activate a 4000-ton electrolytic unit, which started operating in July of that year. Production continued until early 1953, when Government support ceased. Part of the plant was again shut down, but M.E.L. found a way to continue producing on its own account at the rate of 1500 tons per annum in its original plant.

The high cost of electric power, which today is five times the 1938 figure, makes it impossible to operate the established electrolytic processes without subsidy to compete with magnesium available from the U.S., Norway, and Canada.

Intensive efforts are, therefore, being made to find a way to extract magnesium from the dolomite deposits of the U.K. without the use of U.K. electric power. Considerable progress has been made, and it may yet prove possible for this country to have supplies of magnesium from its own dolomite, thus providing an asset of high potential value both to the national economy and to defense.

The United States

The urgent demand from England in 1915 for magnesium metal and powder for flares and tracer bullets at prices of $5 and $6 per lb. induced a number of companies, listed below, to start making the metal, but by 1920 the number had dwindled to two, the American Magnesium Corporation and the Dow Chemical Co.

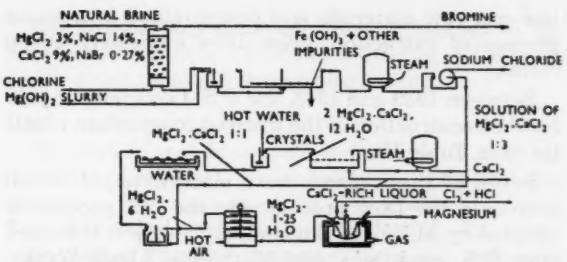

Figure 4. Electrolytic process used by the Dow Chemical Company.

Early American Producers of Magnesium

General Electric Company
Norton Laboratories
Electric Reduction Company
Aviation Materials Corporation
American Magnesium Corporation
Magnesium Manufacturing Corporation
Dow Chemical Company
Shawinigan Electro-Metals Company, Ltd., of Canada

A.M.C. operated the oxide fluoride process developed by Harvey, but the Dow process was cheaper, and produced a purer metal, so A.M.C. ceased production in 1927. Dow continued as the sole primary producer in the U.S. till 1941.

Dr. Herbert Dow, the founder of the Company, began work in 1916 on the problem of extracting magnesium metal from the waste magnesium chloride content of the brine wells in Michigan, from which his Company was already recovering bromine, chlorine, sodium, and calcium. Vast markets were found for these four, and Dr. Dow determined to extract magnesium also and make this a metal of common use. His decision, adopted as a continuing policy by the Dow Co., has helped to make the U.S. the leading world producer and consumer of magnesium.

After overcoming many difficulties, Dr. Dow succeeded in developing an ingenious process for making anhydrous magnesium chloride, in which the hydrated chloride was partly dehydrated by air and then further dehydrated—although not completely—in an atmosphere of hydrochloric acid gas. Fig. 4 depicts a later development of the Dow process. The development of this process was a primary factor in establishing Dow as the leading magnesium producer in the U.S.

In 1940, Dow, advised by E. O. Barstow, decided to make use of the exceptional natural advantages of their Freeport, Texas, site to cheapen magnesium production. Unlimited supplies of low-cost natural gas (providing heat and low-cost electric power), inexhaustible supplies of sea-water and of the purest lime, plus a salt dome for chlorine supply, made Freeport a site *par excellence* for the chlorination of the magnesium hydroxide from sea-water, and the partial dehydration of the resultant $MgCl_2$ to provide the Dow cell feed. This exceptional combination of

low-cost raw materials and power, allied to a sound process of extraction, gives Dow extremely cheap metal.

Between 1939 and 1943, the U.S. Government paid for the construction of the thirteen magnesium plants listed in Table III.

Seven of these plants were electrolytic, of which four used the Dow process, one the I.G. process as adapted by M.E.L. of England, to meet first U.K. and later U.S. conditions, and Mathieson Alkali Works, Inc. and International Minerals and Chemicals Corp. used processes developed by themselves. Of the ferro-silicon units, five operated the process developed by L. M. Pidgeon of Canada, and one a process developed by the Union Carbide and Carbon Corporation. Privately, a 10,700-ton unit was built by Henry Kaiser at Permanente, near San Francisco, to work the carbothermic reduction process of Hansgirg, and the Dow Company expanded its own plants in Michigan and Texas.

TABLE III—*Magnesium-Production Plants Operated in the U.S.A. during World War II*

Location	Operator	Rated Annual Capacity, long tons
Government-Owned Plants		
Electrolytic process:		
Henderson, Nev.	Basic Magnesium, Inc.	50,000
Velasco, Tex.	Dow Magnesium Corp.	32,000
Lake Charles, La.	Mathieson Alkali Works, Inc.	24,000
Ludington and Marysville, Mich.	Dow Magnesium Corp.	32,000
Austin, Tex., and Carlsbad, N. Mex.	International Minerals and Chemical Corp.	11,000
Painesville, Ohio	Diamond Magnesium Co.	16,000
Freeport, Tex. (half plant)	Dow Chemical Co.	8,000
	Total	173,000
Silicothermic process:		
Spokane, Wash.	Electrometallurgical Co.	21,500
Dearborn, Mich.	Ford Motor Co.	17,800
Wingdale, N.Y.	Amco Magnesium Co.	4,500
Manteca, Calif.	Permanente Metals Co.	8,800
Canaan, Conn.	New England Lime Co.	4,500
Luckey, Ohio	Magnesium Reduction Co.	4,500
	Total	61,600
	Grand total	234,600
Privately-owned Plants		
Midland, Mich. (electrolytic)	Dow Chemical Co.	8,000
Freeport, Tex. (half plant electrolytic)	Dow Chemical Co.	8,000
Permanente, Calif. (carbothermic)	Permanente Metals Corp.	10,700
	Total owned plants	26,700

The largest production unit was that of Basic Magnesium Inc., built and operated by a management company comprised of M.E.L. and Basic Refractories Inc. Construction of the giant plant, built in the desert near Las Vegas, Nevada, to use the power from Boulder Dam, began in October 1941, the first metal being produced in August 1942. The Basic Refractories' interest was later purchased by the Anaconda Copper Mining Company, which, in October 1942, took over from M.E.L. the general management and operation of the Company.

The first flotation unit for magnesite ever used in industry was developed and operated successfully by Basic Magnesium Inc. to beneficiate the low-grade magnesite mined at Gabbs, Nevada. The resultant product was a highly reactive, chemically pure material, which greatly improved the efficiencies of the process.

Although the magnesium plant no longer operates, the buildings and services are used for other metallurgical purposes, and Henderson, the town started by Basic Magnesium Inc., is now the third largest city in the State of Nevada.

By 1945, all these plants had been shut down, and the Dow Plant at Freeport, with annual capacity of 18,000 tons, was left as the sole producer.

In 1950, with the Korean crisis, the U.S. was short of magnesium, and six Government-owned plants were re-activated—two electrolytic and four thermal reduction units. Production of pure metal rose to 106,000 short tons in 1952, but fell away after 1953 as the plants were successively closed, only the Velasco and Dow plants remaining in operation. It is estimated that production in 1956 from these plants will approach 70,000 tons.

France

In 1915, under the direction of its President, Henri Gall, the Société d'Electrochimie, d'Electrométallurgie et des Aciéries Electriques d'Ugine erected at Clavaux, Isère, the first plant in France for the extraction of magnesium from magnesium chloride by the electrolytic process, and in 1916 production reached 25 tons. In 1922, the Compagnie Alais, Froges et Carmargue, now Péchiney, erected a similar plant at Epierre, in Savoie.

These two plants were later replaced by the more important plants of Jarrie, Isère, and of Saint-Auban in the Basses-Alpes, which before and during the first years of World War II produced 3000 tons per annum, using the I.G. Farbenindustrie's thermal electrolytic process. Under the occupation, this figure dropped to 400 tons per annum in 1944. Since the war, only the Jarrie works has been operating, with an annual production of 1500 tons, the balance of France's requirements being covered by imports.

During the period 1931–38, reduction of oxidic compounds of magnesium by mixing the compound with silicon or ferro-silicon, pressing into pellets, and heating the pellets to effect reduction, was being undertaken on a laboratory scale by Messrs. Gire and Fouquet, who patented this process.[3] Fouquet later took out a patent for the thermal reduction process, but no large-scale production developed.

Since the war, the cost of electric power in France has risen to a height which makes it difficult to operate economically the thermal electrolyte process. Considerable study and research has resulted in the development of a new type of thermal reduction which differs in its essentials from those at present used. Pilot-scale trials have given most interesting figures and have created hopes that when operated

on a commercial basis this process will produce magnesium to sell at world price.[4]

Canada

Magnesium was first made by Shawinigan Electro-Metals Company at Shawinigan Falls, Quebec, in 1915, from materials imported from the U.S.A. This plant operated until 1919, when it was closed down.

In 1941, L. M. Pidgeon successfully produced high-purity magnesium from dolomite by the ferro-silicon reduction process on a pilot-plant scale, using 4-in.-dia. retorts. The Canadian Government and a group of Canadian Mining Companies provided the capital, and in August 1942 a plant with a capacity of 5000 tons per annum was built and operated by the Dominion Magnesium Company at Haley, Ontario. The designed capacity was substantially exceeded. This successful translation of the Pidgeon process from pilot-scale to commercial production in such a relatively short time was a remarkable achievement, of great value to Canada and the U.S.A., where five similar plants were built (see Table III).

The Aluminium Company of Canada now operates a thermal electrolytic plant at Arvida, Quebec, which uses brucite extracted from brucitic limestone as the raw material. This company uses chlorinators and cells of its own design and construction, which differ fundamentally from both the I.G. and Dow designs.

During the period 1939–45, the Consolidated Mining and Smelting Company of Canada produced considerable quantities of magnesium powder for use in pyrotechnics.

Australia

In 1940, under the management of Broken Hill Proprietary, Ltd., a plant to extract magnesium from magnesium oxide using calcium carbide as the reducing agent in high vacuum, at temperatures between 1200° and 1400° C., and based on the Murex process, was erected at Newcastle, New South Wales. Production started in July 1941 and continued at a rate of 600 tons per annum until May 1944, when it was shut down. The foundry and magnesium powder plant continued in operation until September 1945.

Norway

The sole producer is the Norsk Hydro-Elektrisk Kvoelstofaktieselskab at Heroya on the Oslo Fiord.

The plant was built by the Germans during the occupation to produce 10,000–12,000 tons per annum, but was bombed heavily before it started and produced no metal. It was rebuilt after the war with a completely new plant to produce magnesia from sea-water, and with new-type cells one and a half times the capacity of the original I.G. cells.

The magnesia plant started in the spring of 1951, and the first metal was produced in the autumn of that year. Present production is 7000–8000 tons per annum and will eventually reach 12,000 when in full operation.

The Norwegians have the great advantage of an excellent site with low-cost raw materials and power, which gives them a low-cost magnesium.

Italy

Magnesium was first made in Sardinia in 1937 by the Samis Company, but at too high a cost and the plant was soon shut down. In 1939 the Samis/Aosta Company was formed to operate the I.G. dolomite/ferro-silicon thermal reduction process, and produced some 350 tons per annum until 1945, when it was closed.

The Società Anonima Italiana per il Magnesio e Leghe di Magnesio was founded in 1938 to erect a plant at Bolzano to operate the Amati process for the extraction of the metal from the oxide. This Company is today the sole producer of magnesium in Italy, extracting magnesium from dolomite by a thermal process using ferro-silicon as developed by Edoardo Ravelli, with a potential capacity of 4000 tons per annum. The estimated tonnage produced in 1955 was 1200 tons.

Switzerland

The S.A. pour la Fabrication du Magnésium is said to have produced metal in small quantities at its Martigny-Bourg plant from 1926 until 1947, when there was a break for two years. Production is said to have begun again in 1952, and small quantities are still being produced. The output of the Martigny-Bourg plant never exceeded 500 tons per annum, and this was used almost entirely for alloying with aluminum.

Russia

Statistics for 1955 credit Russia with a production of 50,000 long tons per annum. There is no information available relative to the size and site of the plant or plants, and the processes worked, but since the Russians acquired the processes of the I.G. before the outbreak of World War II, it is probable that the metal is produced by the I.G. thermal electrolytic process.

Japan

Production of magnesium in Japan ceased at the end of the war, but has again been started at the Riken Kinzoyu Company's magnesium plant at Ube. This plant now derives most of its raw material from sea-water and uses an electrolytic process based on that of the I.G.

Korea

The Nippon Magnesium Kuizoku Kabushiki Kaisha in 1938 built a plant to operate the carbothermic process of Hansgirg. The designed capacity was 6 tons per day. By the end of 1938 it was operating at approximately 40% of its designed capacity, and it is believed to have done better during World War II. The date of closing is not known.

The facts given above show that at present the Dow Chemical Company of the U.S. and the Norsk-

Hydro of Norway are probably the two lowest-cost producers, because of their inherent natural advantages, and they both use electrolytic processes. The main difference between the Dow and I.G. processes lies in the fact that the Dow process uses partially hydrated magnesium chloride as cell feed, whereas the I.G. process uses completely anhydrous magnesium chloride. The Dominion Magnesium Company of Canada and the Società Anonima Italiana per il Magnesio et Leghe di Magnesio both continue to extract metal from dolomite by the ferro-silicon thermal process, and their ability to compete with the electrolytic metal is again due to great natural advantages. Much research effort continues to be devoted to lowering the present costs of direct thermal extraction processes, and one of these may yet prove to be lower in cost than the electrolytic.

MAGNESIUM ALLOYS

The crystal lattice structure of magnesium is close-packed hexagonal, and the metal is generally obtainable in commercial quality in minimum purities of 99.8 and 99.95% by electrolytic and thermal extraction, respectively.

Pure magnesium is not sufficiently strong to be used by itself for engineering purposes, although it is widely used as an alloying constituent with other metals, and for refining other metals. The tensile strength of pure magnesium in the sand-cast state is only 7 tons/in.^{2} and about 13 tons/in.^{2} when extruded.

By the addition of comparatively small quantities of selected elements, however, alloys of magnesium can be produced whose mechanical properties are so much higher than those of the pure metal that, when considered in conjunction with their light weight and outstanding machinability, the use of them is attractive to engineers and constructors.

Until the end of the last war, the elements most widely used for alloying with magnesium were aluminum, zinc, and manganese; aluminum and zinc as hardening agents to improve the strength properties, and manganese to improve the corrosion-resistance.

The first alloys of magnesium, containing aluminum and zinc, were produced by Griesheim-Elektron at Bitterfeld and shown in 1909 at the International Aircraft Exhibition at Frankfurt. Considerable tonnages were used for munitions by Germany in 1914–18, but their high cost and low corrosion-resistance prevented any real progress until 1928. During this period some progress was made in the U.K. by The British Maxium Co. and by F. A. Hughes and Co. and Sterling Metals, Ltd., of Coventry, the latter of whom cast the magnesium crankcases for the Napier "Lion" engines fitted to the Super-marine seaplanes which won the Schneider Cup for Britain in 1927.

In 1923 the Bitterfeld team discovered that magnesium could be melted and refined by using high-viscosity fluxes which absorbed non-metallic impurities such as oxides, nitrides, and chlorides, but which remained sufficiently viscous to avoid retention in, or pouring with, the metal. This discovery, which greatly improved the quality of the product, marked a notable advance in melting techniques.

In 1925 Boyer, in the U.S., and Beck, in Germany, working independently, made the important discovery that addition of an excess quantity of manganese to molten magnesium not only precipitated impurities such as iron, but also greatly increased the corrosion-resistance of the resultant alloy. In 1926, the British Air Ministry recognized the progress made by issuing specification D.T.D. 59 for the alloy known as A8, and it is from the year 1927 that expansion of use of these first magnesium alloys in the U.K. really dates.

One of the first casting alloys—which is still fairly widely used—contained aluminum 6, zinc 3, manganese 0.3%, remainder magnesium. This alloy had good corrosion-resistance but a strong tendency to microporosity. In Europe and the U.K., it was early replaced by alloys containing 8 or 9% aluminum and only 0.4% zinc, because the lower zinc content greatly reduced the risk of microporosity.

A complete and detailed description of all the original work of the Bitterfeld group is to be found in the book by Dr. Adolf Beck, which was subsequently translated into English.[5]

Tables IV and V show typical chemical compositions and tensile properties of the magnesium-manganese and magnesium-aluminum-zinc-manganese standard casting and wrought alloys as used in the U.K., which are typical for these alloys in all countries.

After World War II, it was found that none of the established alloys could meet the demand of designers and constructors of the new types of airframes and turbine engines, the former of whom required alloys of much greater strength, and the latter, alloys which would retain their properties at elevated temperatures and possess higher resistance to creep. Between 1928 and 1946, although many hundreds of patents had been taken out, no new magnesium alloys of outstanding merit were developed commercially.

In 1938, the Bitterfeld Group showed me the very marked grain refinement obtained by alloying zirconium with magnesium, in accordance with the initial findings of Professor Sauerwald. Hitherto grain refinement had been obtained with the magnesium-aluminum alloys by superheating melts to temperatures above 850° C., an empirical procedure, the fundamental reasons for which still remain unclarified.

The prospect of having a grain-refining process of far greater intensity and more susceptible of understanding and control was most attractive, and its successful introduction could exercise a profound effect in accelerating the general acceptance of magnesium by those designers and constructors who

TABLE IV—*Typical Chemical Compositions and Tensile Properties of Elektron Standard Casting Alloys*

Typical Chemical Composition			Elektron Alloy		Specification	Tensile Properties		
Al, %	Zn, %	Mn, %				0.1% Proof Stress, tons/in.²	Ultimate Stress, tons/in.²	Elongation, % on 2 in.
8.0	0.5	0.3	A8	As-Cast	B.S. L121 (Aircraft) B.S. 1277 (Gen. Eng.)	4.5-5.5	9.0-11.0	2- 5
				Solution-treated	B.S. L122 (Aircraft) B.S. 1278 (Gen. Eng.)	4.5-5.5	13.0-17.0	6-15
9.5	0.5	0.3	AZ91	As-cast	B.S. L123 (Aircraft) B.S. 1273 (Gen. Eng.)	4.5-6.0	8.0-10.5	1- 3
				Solution-treated	B.S. L124 (Aircraft) B.S. 1274 (Gen. Eng.)	5.0-6.0	13.0-16.0	4- 8
				Fully heat-treated	B.S. L125 (Aircraft) B.S. 1275 (Gen. Eng.)	6.5-8.5	13.0-16.5	1- 4
7.5-9.5	0.3-1.5	0.15 min.	C	As-cast		4.0-5.5	8.0-11.0	2- 5
				Solution-treated		4.0-5.5	12.0-16.0	4-10
				Fully heat-treated		5.0-7.5	13.0-16.0	1- 3

TABLE V—*Typical Chemical Compositions and Tensile Properties of Elektron Standard Wrought Alloys*

Typical Chemical Composition			Elektron Alloy		Specification	Tensile Properties		
Al, %	Zn, %	Mn, %				0.1% Proof Stress, tons/in.²	Ultimate Stress, tons/in.²	Elongation, % on 2 in.
		1.5	AM503	Plate, sheet, and strip	D.T.D. 118A B.S. 1353 (Gen. Eng.)	5.0-10.0	13.0-18.0	5-14
				Extruded bars and sections	D.T.D. 142A B.S. 1355 (Gen. Eng.)	8.0-13.0	15.0-20.0	4-10
				Extruded tube	D.T.D. 737 B.S. 1357 (Gen. Eng.)	9.0-11.0*	15.0-17.0	4- 6
6.0	1.0	0.3	AZM	Extruded bars and sections <3 in.	D.T.D. 259A B.S. 1354 (Gen. Eng.)	11.0-14.0	17.0-22.0	10-18
				Extruded bars and sections >3 in.	D.T.D. 749 B.S. 1354 (Gen. Eng.)	9.0-12.0	14.0-19.0	8-16
				Extruded tube	D.T.D. 348A B.S. 1356 (Gen. Eng.)	10.0-12.0*	17.0-20.0	8-12
				Forgings	D.T.D. 88C B.S. 1351 (Gen. Eng.)	10.0-13.0	18.0-20.0	8-14
8.0	0.4	0.3	AZ855	Press-forgings	D.T.D. 88C B.S. 1351 (Gen. Eng.)	10.0-14.0	18.0-22.0	8-14

* 0.2% proof stress.

TABLE VI—*Typical Chemical Compositions and Tensile Properties of Elektron Zirconium-Containing Casting Alloys*

Typical Chemical Composition				Elektron Alloy		Specification	Tensile Properties		
Zr, %	Rare-Earth Metals, %	Th, %	Zn, %				0.1% Proof Stress, tons/in.²	Ultimate Stress, tons/in.²	Elongation, % on 2 in.
0.7	...	...	4.5	Z5Z	As-cast	D.T.D. 711A	7.0- 8.5	13.0-17.0	7-15
					Heat-treated	D.T.D. 721A	8.5-10.5	15.0-18.0	5-12
0.7	1.2	...	4.0	RZ5	As-cast	D.T.D. 738	5.5- 6.5	11.0-12.0	3- 6
					Heat-treated	D.T.D. 748	8.0- 9.0	13.0-14.5	3- 5
0.7	...	1.8	5.5	TZ6	Heat-treated	D.T.D. 000 (Draft M40)	9.5-11.0	17.0-19.5	5-15
0.6	2.7	...	2.2	ZRE1	As cast and annealed	D.T.D. 708	5.0- 6.0	9.0-11.0	3- 6
0.6	3.0	...	...	MCZ	As cast and annealed	D.T.D. 728	5.0- 6.0	9.0-10.5	3- 6
0.7	...	3.0	2.2	ZT1	Heat-treated	D.T.D. 5005	5.0- 6.0	12.0-14.0	5-10

wished to use ultra-light materials.

Although the Bitterfeld Group had made the initial discovery, they found that the problem of effectively and economically introducing zirconium into magnesium alloys via reducible salt mixtures without the formation of persistent and corrosive flux inclusions and objectionable microporosity was not easily solved. Early in 1939 they recommended M.E.L. to stop working on the problem and finally, in about 1942, abandoned it as impracticable. It is probable that war-time conditions influenced their assessment of the difficulties.

Because the history of steel supported the belief that the further progress of magnesium alloys must depend upon progress in grain refinement, despite the pressure of the war years, the M.E.L. staff continued to study this problem as time and opportunity offered.

A. C. Jessup, who had a life-long association with the magnesium industry, then Chief Metallurgist of M.E.L., directed with great ability and foresight the research team which developed the magnesium-zirconium and later the magnesium-thorium alloys.

The problems encountered were complex and as much chemical as metallurgical in nature. As no existing source of metallic zirconium could be alloyed effectively with magnesium, in the U.K. the M.E.L. chemical team, led by A. L. Hock, had first to produce reducible zirconium compounds. Fluoride salt mixtures, which would be non-corrosive toward magnesium if entrapped, offered the greatest hope of success, but eventually fluoride-chloride mixtures were devised which did not become entrained in the metal, and fluozirconates were produced at a cost which made it possible to supply the zirconium-containing alloy at reasonable prices. New high-density fluxes were also developed which virtually eliminated the risk of chloride contamination. The difficulties encountered and progress made in developing the new range of magnesium-zirconium alloys are described more fully elsewhere.[6, 7]

Additions of the rare-earth metals to the binary and ternary alloys were studied, and alloys were developed which had greatly improved properties at elevated temperatures. Murphy and Payne,[8] of J. Stone and Co., London, contributed valuable pioneer work at this time in high-temperature alloy formulation. To obtain optimum properties, the effective zirconium content must be maintained at 0.6–0.7%. Since some loss both of zirconium and of the rare-earth metals content occurs on melting, processes were devised to provide for the revivification in a simple manner of both the zirconium content and the rare-earth metal content by the addition of special salts to the melts, so that foundry personnel have little more difficulty in handling zirconium alloys than those of the older types.

The purely metallographic side of magnesium-zirconium alloys is of interest. A number of insoluble zirconium-rich phases may be present, and the elucidation of the compositions of these has involved much work. Zirconium alloys show peculiar forms of coring and the relations between coring and grain boundaries are sometimes most curious and complex.

Casting alloys of magnesium-zirconium with zinc have proof stresses nearly double those of the original alloys (Table VI), and test-bar tensile properties are often reached and even exceeded in pieces cut from actual castings. The alloys also show much reduced notch sensitivity in fatigue.

Additions of the rare-earth metals to the magnesium-zirconium base give a range of alloys easily cast, which combine excellent high-temperature properties with complete freedom from microporosity. The soundness of the castings is such that, despite the higher price, these alloys are often used for applications at normal temperatures.

In view of the quite remarkable improvement in working properties obtained by the addition of zirconium to magnesium alloys disclosed by early experiments, in 1946, M.E.L. decided that suitable ingots and billets should be submitted to severe working tests. With the kind co-operation of Dorman Long and Co., ingots were cast in alloy containing zirconium and zinc and weighing some 1200 lb. or 7 times the normal slabs then used. These ingots were rolled at Acklam steel mill to give nearly 300-ft. lengths of 2-in.-sq. bar without loss. This bar was then rolled down by the Darlington Rolling Mills on high-speed steel-section rolling mills at speeds of 600 ft./min. to give various shaped sections as for the steel bar, proving that these new alloys could be rolled on steel equipment at steel speeds by men who had never handled magnesium alloys before. These results, which astonished all who saw them, marked a most important turning point in the development of wrought magnesium products because, for the first time, and contrary to all established theory and practice, which insisted that magnesium must be deformed slowly, these full-scale trials proved that, given sufficient power, magnesium alloys can be rolled easily and quickly at the right temperature.

The experience thus obtained has been applied in sheet rolling mills in this country, where slabs are broken down from 5 in. thickness to 0.25 in. blank in one heat, as simply and easily as for pure aluminum. A distinctive characteristic of such breaking-down is the complete absence of edge-cracking. These alloys can be extruded at 100 ft./min. into most complicated sections, but highest values are obtained at the speeds used for high-strength aluminum alloy. Typical compositions and properties of the wrought alloys containing zirconium are shown in Table VII.

In 1946 I ventured to forecast that, as the new zirconium-containing alloys became better known and their properties more widely appreciated, usage by the aircraft industries of the world would overtake gradually that of the older alloys. As will be seen from Fig. 5, which shows the growth of usage

of the rare-earth-containing alloys and the straight magnesium-zirconium-zinc alloy known as Z5Z, British experience has confirmed the accuracy of this forecast. Foundries in the other countries which have taken licences to use the fluoride alloying processes developed by M.E.L. are experiencing the same kind of growth in demand.

Soon after the close of World War II, the Dow Company also began to examine the potentialities of alloying zirconium with magnesium. Because of the availability of a cheaper and assured source of zirconium chloride, the Dow Company decided to use these salts to enable them to proceed more rapidly in the wrought field. They developed the well-known alloy ZK60, which in extruded form has been used so successfully in large quantities by the U.S. aircraft industry. Later, the Dow Company and American Magnesium Corporation decided to make master alloys of magnesium and zirconium alloys for introducing zirconium.

The Dow Co. also developed magnesium-rare-earth-metals-zirconium casting alloys for elevated-temperature use. The original alloy contained only a small zirconium content, but this was later increased and zinc was added to give a composition corresponding to that of the British alloy ZRE1, and the Dow Co. now have a range of these alloys in regular production.

In the summer of 1946 the Dow Company arranged with the American Rolling Mill Company's mills at Butler to hold a series of experimental continuous-rolling tests. The cast slabs used at Butler weighed 850 lb. and were passed through a reversing breakdown mill with a speed and power such that the slabs, instead of losing heat, gained heat in the 2 min. required for rolling from 7 to 0.4 in. This plate, passing on heat to the tandem mill, emerged a minute later as 0.05-in. sheet, and was rolled at 1200 ft./min. Encouraged and fortified by the success of this experiment, the Dow Co. determined to design and develop a continuous rolling mill of great size, and so reduce the high cost of rolled magnesium sheet produced by the small mills operating to date.

At Madison, near St. Louis, the Dow Co., in November 1953, began to operate a 50-million-dollar, fully mechanized plant for semi-continuous coil rolling, extrusion, and ingot-making. The rolling mill has an annual capacity of 8000 tons of 0.032-in. sheet, 6000 tons of extrusions, and 18,000 tons of alloy ingot. Notable items of equipment are an 84-in. reversing breakdown coil mill which hot rolls 2000-lb. direct-chill continuously cast slabs at speeds up to 1100 ft./min. A 13,200 ton extrusion press is also in regular operation.

I was privileged to attend the official opening of the Madison mill in May 1954, which was a great occasion and marked a tremendous step forward in sheet production. The magnesium industry of the world will always feel indebted to the Dow Co. for proving that magnesium can be rolled both easily and cheaply, at prices per unit volume comparable with aluminum.

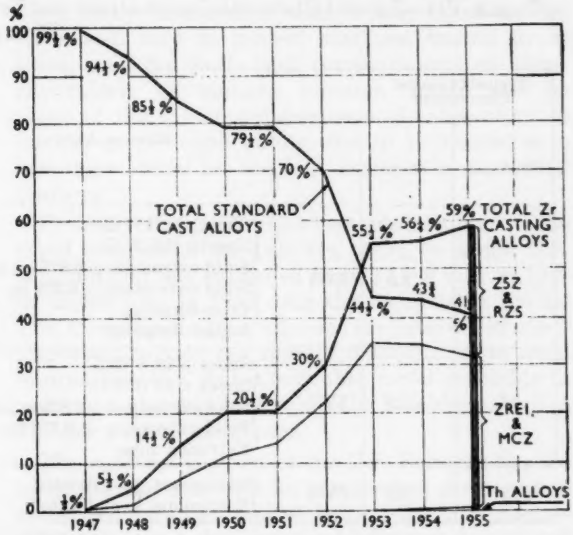

Figure 5. Comparative sales of zirconium and non-zirconium casting alloys for aircraft purposes.

TABLE VIII—*Tensile Properties (at Room Temperature) of ZT1 Compared with ZRE1/MCZ*

Alloy	0.1% Proof Stress, tons/in.²	Ultimate Stress, tons/in.²	Elongation, % on 2 in.
ZT1	5.5–6.5	12.0–14.0	5–10
ZRE1/MCZ	5.0–6.0	9.0–11.0	3– 5

The initial discovery of Sauerwald [15] in 1940 that thorium has a beneficial effect on the creep-resistance of magnesium has led to the simultaneous development in the U.K. and the U.S.A. of an important range of alloys.[9-11]

The work of M.E.L. proved conclusively that the addition of zinc to the magnesium-zirconium-thorium

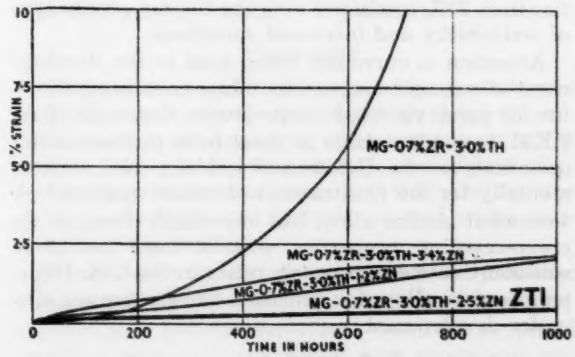

Figure 6. Effect of zinc additions on the creep-resistance of magnesium—0.7% zirconium—3.0% thorium alloy. Temperature 320° C.; stress 1½ tons/in.²

TABLE VII—*Typical Chemical Compositions and Tensile Properties of the Elektron Zirconium-Containing Wrought Alloys*

Typical Chemical Composition			Elektron Alloy	Specification	Tensile Properties		
Zr, %	Zn, %				0.1% Proof Stress, tons/in.²	Ultimate Stress, tons/in.²	Elongation, % on 2 in.
0.7	3.0	ZW3	Sheet >18 S.W.G.	D.T.D. 626A	11.0–14.0	17.0–20.0	8–18
			Sheet <18 S.W.G.	D.T.D. 626A	10.0–12.0	16.0–18.0	...
			Solid extrusions >0.375 in. and up to 4 in.	D.T.D. 622A	14.0–17.0	20.0–23.0	10–25
			Solid extrusions <0.375 in.	D.T.D. 622A	12.0–15.0	18.0–21.0	10–15
			Press-forgings	D.T.D. 619	13.0–15.0	19.0–22.0	8–14
			Impact-forgings	D.T.D. 729	11.0–14.0	17.0–20.0	8–12
0.7	1.3	ZW1	Sheet >18 S.W.G.	D.T.D. 5001	10.0–12.0	16.0–18.0	8–18
			Sheet <18 S.W.G.	D.T.D. 5001	9.0–11.0	15.0–17.0	...
			Solid extrusions >0.375 in. and up to 2 in.	D.T.D. 5011	11.0–14.0	17.0–20.0	10–20
			Solid extrusions < 0.375 in.	D.T.D. 5011	10.0–12.0	16.0–18.0	10–15
			Extruded tube	D.T.D. 5021	11.0–14.0*	16.0–20.0	4–15
0.7	5.5	ZW6	Extrusions, as-extruded	D.T.D. 5031	13.0	19.0	10
			Extrusions, heat-treated	D.T.D. 5041	14.0	20.0	8

* 0.2% proof stress.

system to provide a certain zinc : thorium ratio, greatly improved the long-term creep-resistance of these alloys in the cast state at elevated temperatures (Fig. 6), thus leading to the alloy ZT1. However, for short-term applications at more moderate temperatures, the zinc addition may best be omitted.[12] The addition of zinc results in a marked modification of the metallographic structure of magnesium-zirconium-thorium alloys, and the amount of the new phase in the structure is related to the zinc : thorium ratio and the long-term creep-resistance. To obtain optimum creep-resistance, the zinc addition must be closely controlled in relationship to the thorium content. The room-temperature mechanical properties of the alloy ZT1 are also generally superior to those of the alloys containing-rare-earth metals (Table VIII). Castings in ZT1 alloy are now in operation in both British and American jet engines. Further exploration of the magnesium-zirconium-zinc-thorium system produced another alloy, TZ6,[13] distinguished by having even higher normal-temperature properties than Z5Z, combined with the further advantages of weldability and increased soundness.

Attention is currently being paid to the development of wrought magnesium alloys containing thorium for use at elevated temperatures. One such alloy, HK31, is now available in sheet form in commercial quantities in the U.S.A. and is being used experimentally for the construction of ramjet engines.[14] A somewhat similar alloy, but one which develops its creep-resisting properties without need for prior solution-treatment, is nearly ready in the U.K. High-temperature alloys for extrusion and forging are also under development.

APPLICATIONS OF MAGNESIUM

As history records, the quantities of magnesium used up to 1927 for all purposes, including World War I, were quite small and not enough to support an industry.

During the next ten years intensive effort by the manufacturers aroused the interest and support of some pioneer fabricators, and a small commercial usage was added to the military requirements of the various countries producing the metal.

Much good work was accomplished, and by their quality of performance magnesium alloys won from engineers and constructors gradual acceptance and recognition as the lightest construction materials.

Then came the sudden and immense demands of World War II which changed completely the status of magnesium and opened the way to its present rapid progress.

Hundreds of fabricators to whom magnesium alloys were previously unknown, were trained to use them for war production, and thus became aware of their advantages over other metals and their potentialities for civilian usage.

Experience shows that the performance of fabricated and wrought products of magnesium has been so satisfactory that engineers and constructors have grown to have greater confidence in the metal as an engineering material. The importance of lightness is becoming increasingly recognized—a great advantage to magnesium, which weighs one-third less than aluminum. Many fabricators throughout the world are now promoting the use of the metal by spending money to advance its technology, and no longer depend solely on the efforts of the producers.

Some outstanding applications of magnesium which have absorbed large tonnages and which by their very success have aroused the interest of engineers everywhere, are:

(*a*) The use in all countries of magnesium alloys for aircraft landing wheels, of which approximately

one million were cast for British aviation alone during the war. Despite the most severe conditions, there were practically no service failures.

(*b*) The 36 lb. of finished magnesium castings used in the engine of the Volkswagen car, probably the largest single use of magnesium in the world. During 1955 the Volkswagen foundries used over 8000 tons of magnesium.

(*c*) In the U.K. the 52-lb. transmission case for the Standard Ferguson tractor. Since the start in 1947, nearly 600,000 of this highly stressed casting, which is the backbone of tractor, have gone all over the world in Ferguson tractors, and the magnesium alloy used has proved itself fully equal to the rough usage and adverse conditions to which it has been exposed, with no known failures.

These are outstanding examples of the satisfactory usage of magnesium alloys as castings, but many thousands of tons of magnesium castings have given excellent service all over the world in aircraft and vehicle engines, in airframes, bodies for heavy vehicles, and in many other fields where lightness and outstanding machinability are important. Nearly all jet and propeller turbine engines incorporate ZRE1 or similar magnesium alloy castings. To take just one example: the famous Rolls Royce "Dart," which powers the Vickers "Viscount" airliner, carries 82 ZRE1 castings.

In civilian fields, the classical magnesium-aluminum-zinc alloys are used extensively for components in textile machinery, portable tools, vacuum cleaners, cameras, binoculars, etc. The figures and tables given earlier in this paper show the important part the new zirconium alloys are playing in expanding usage by the aircraft industry.

Wrought magnesium was used in great quantities during the last war for parts of airframes and welded petrol and oil tanks, and is today being used in greater quantity, particularly in the U.S. and Russia, for parts of the fuselage and wings of many aircraft.

Large quantities of thick sheet are being used for heavy-vehicle bodies, and a particularly interesting development is the growing use of magnesium sheet in the printing trades, because of its admirable etching qualities.

Equipment suppliers are becoming magnesium-minded, and the machine-tool industry is beginning to realize the great advantages that can accrue from magnesium's very high machining rates.

Magnesium is being used in steadily increasing quantities for alloying with aluminum, and in large tonnages as the reducing agent to extract metallic titanium from titanium tetrachloride by the Kroll process.

The high contact potential of magnesium and its freedom from polarization effects, make it the ideal metal to employ as galvanic anodes for the cathodic protection of corrodible metals, particularly iron and steel. Many thousands of tons of magnesium anodes have been used to protect pipelines, buried structures, and the hulls and compartments of ships, particularly oil tankers. Mention should also be made of the growing importance of magnesium in nuclear-power applications, and in particular as a canning material for the fuel elements in gas-cooled reactors.

Probably the most important contribution to the rapid progress of the past ten years, in which U.S. consumption has expanded from 13,000 tons in 1946 to 65,000 tons in 1956, was the recognition by the U.S. Government that, whereas ore reserves of many important metals are rapidly diminishing, in magnesium the U.S. has a valuable metal available in unlimited quantity both within its boundaries and in the sea washing its shores.

The constant support of the U.S. Services has led to substantial demands for magnesium sheet, extrusions, and forgings, and so helped the U.S. magnesium industry to become the leading producers and fabricators in the world.

Dr. Hanawalt, of Dow, records that in 1955 civilian consumption for the first time reached 53% of the total consumption of magnesium products in the U.S. This achievement in a year which saw the highest U.S. consumption yet recorded at 65,000 tons, confirms the value and size of the Government support, and demonstrates the great advantage of having supplies of wrought materials at prices which permit the fabricated part to be sold as cheaply as aluminum. In the U.K., where at present the defense interest is less than in the U.S.A., the proportions for the last few years have been approximately 25% for defense and 75% for other uses.

The U.S. forecasts are that consumption in the U.S. alone will reach 100,000 tons by 1960, but it is unlikely that the rate of progress in Europe will parallel that of the U.S. until the selling price of wrought products compares with that in the U.S.

It should be noted that the U.S. President's Materials Policy Commission foreshadows a U.S. consumption of 384,000 tons per annum by 1975, which the U.S. industry thinks is a reasonable estimate.

CONCLUSION

This summary of the progress of magnesium and its alloy shows clearly how rapid has been the advance in the past ten years, more particularly in the U.S.A., where fabricators are now so confident of an assured and expanding usage that they are working hard on developments to find new and wider markets for their products.

Examination of all the various known processes shows conclusively that low-cost production of magnesium is at present dependent upon the supply of low-cost power in conjunction with ample raw materials.

Constructors of aircraft and aero-engines will be

users of magnesium alloys so long as these meet their technical requirements, and the saving of weight remains as important an economic factor as it is today, when 1 lb. extra payload may be worth £30 or £60 according to the speed of the air-liner.

After more than 30 years' experience of magnesium, I remain more convinced than ever that as the inherent advantages of this lightest of metals become more widely known, the demand will rapidly increase, extraction and fabricating costs will be lowered, alloys will be further improved, and the future progress of magnesium will parallel or even improve upon that of aluminum.

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The USS NAUTILUS (SSN-571) will be refueled for the first time this spring, the Navy announced today.

Special equipment and techniques will be used to perform history's first atomic ship refueling operation. NAUTILUS is designed to permit refueling during any normal overhaul period.

The present uranium core of the NAUTILUS's reactor will be removed and a new core installed. The old core will be sent to Arco, Idaho, for examination and to reclaim unused uranium.

The NAUTILUS first got underway on nuclear power January 17, 1955. Since then, the NAUTILUS has steamed over 55,000 miles from power generated by her reactor.

G. L. GRAVES and D. TEMPESCO

DESIGN CONSIDERATIONS FOR LIGHT WEIGHT GAS TURBINES WITH REGENERATION

THE AUTHORS

Mr. G. L. Graves graduated from New York University in 1949. He started in the Bureau of Ships as an engineer trainee and is now head of the Component Section of the Gas Turbine Branch. He presented a previous paper on "Design Considerations for Naval Gas Turbines" to the ASME 1956 Gas Turbine Power Meeting in Washington, D. C. (Paper GTP-1). This paper was reprinted in the August 1956 A.S.N.E. Journal.

Mr. D. Tempesco is an engineering senior at Pennsylvania State College. This work was done while Mr. D. Tempesco was a summer engineering trainee in the Bureau of Ships, Gas Turbine Branch.

IT SEEMS that any discussion of the application potential of gas turbines begins and ends with the problem of fuel consumption. The use of heat exchangers offers a partial solution to this problem. There are two main types of heat exchangers:

a. Rotary regenerators, in which some suitable substance such as wire mesh is exposed alternately to hot and cold gases.

b. Recuperators, in which two streams of gas or air are separated by a comparatively thin wall through which heat passes by conduction.

In this discussion both types of heat exchangers will be referred to as regenerators. Regenerator development has reached the point where it is practicable to use light weight recuperators of 60–70 per cent effectiveness or rotary regenerators of 80–90 per cent effectiveness with gas turbines for naval and other applications.

In considering a regenerator the following questions must be asked:

a. How important is the added complication of a regenerator for the specific application?

b. How can this complication be compromised or minimized?

The added weight, probable failure of brazed joints due to thermal stresses, additional control problem due to thermal lag and the core fouling problem are a few of the complications which must be considered. Since the reliability of an engine should not be compromised, more conservative heat exchanger designs with lower effectiveness should be used.

The complexity of the core section affects the manufacturing cost and manufacturing quality control. For some of the more advanced high performance core designs, critical sections are brazed and the quality control of the brazed joint is dependent on the type of braze and manufacturing facilities available. Brazed joints are subject to thermal stresses. High temperature brazes are brittle and are subject to failure. A deterioration of performance results due to leakage.

It is also necessary to design core sections for minimum fouling and easy disassembly for periodic cleaning. The fouling of regenerators is a major problem for some designs primarily because of the possibility of steel fires in the cores. The carbon depositing on the gas side sometimes catches on fire and heats up the metal core. The core then oxidizes

very rapidly. The effect is similar to the phenomena of catastrophic oxidation. A number of such fires have occurred in actual practice.

The importance of pressure loss in gas turbine cycles leaves little room for compromise. The pressure loss due to duct sections and headers is chargeable against the regenerator. The importance of low duct and header losses must be emphasized. On the high pressure side each one per cent of pressure loss is more detrimental to overall thermal efficiency than one percent lower turbine efficiency. The per cent pressure loss on the low pressure side of the regenerator is less important. In general, the power losses due to a percentage of pressure loss in the high and low pressure sides of a regenerator are proportional to the turbine inlet and exhaust temperature levels respectively.

For light weight regenerators low pressure drops are not compatible with the requirements for effectiveness (90% or higher). Low pressure drops mean lower velocities, low heat transfer rates and larger heat transfer areas for a given effectivenesss.

To show the advantages of a gas turbine power plant with regeneration and to make a comparison of this plant with that of a simple cycle gas turbine power plant various cycle calculations were made using the following assumptions:

Ambient temperature	80° F.
Compressor inlet pressure	14.55 psia.
Turbine exhaust pressure	14.92 psia.
$\triangle P/P$ combustor	5%
Combustor efficiency	98%
$\triangle P/P$ gas side of regenerator	2%
$\triangle P/P$ air side of regenerator	2%

A cycle diagram for a regenerated gas turbine is shown in Figure (1). The pressure loss in the regenerator will cause a decrease in the pressure ratio across the turbine, which will lower the turbine power output. For a given engine design it is reasonable to establish an application weight and size limitation and a maximum acceptable power or regenerator pressure loss. Since the pressure losses are assumed constant, regardless of the level of effectiveness, the work output curves of figure (2) apply to the several levels of effectiveness studied. The optimum pressure ratio for maximum work output varies with the level of component efficiency. The work output per pound of air is less than that for a simple cycle engine. Even for the low pressure drops assumed in these calculations, the work loss is appreciable.

Preheating the combustion air by using a heat exchanger to extract heat energy from the exhaust

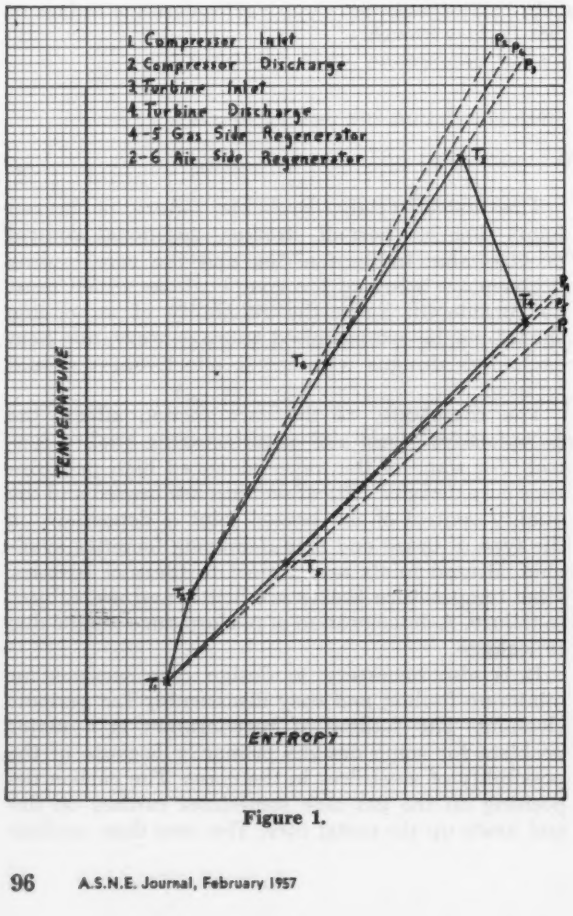


Figure 1.

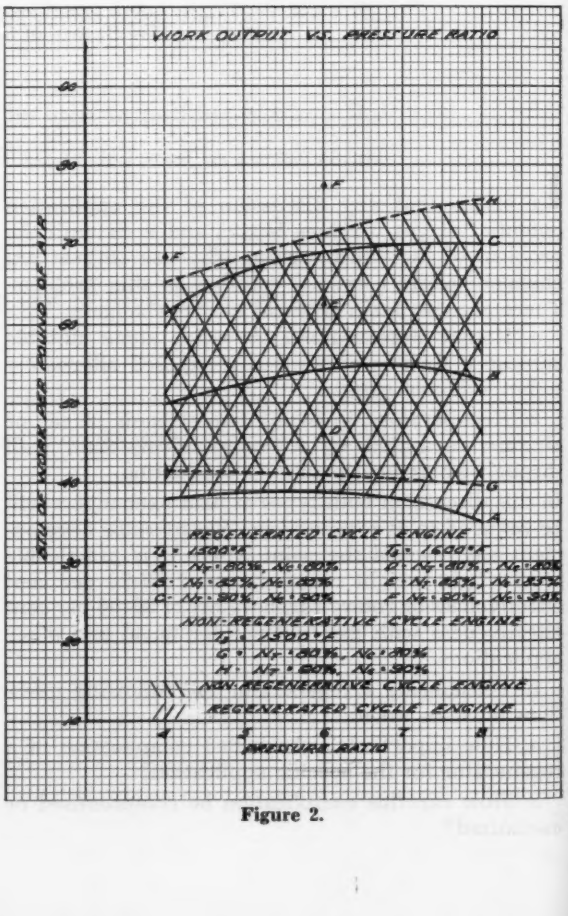


Figure 2.

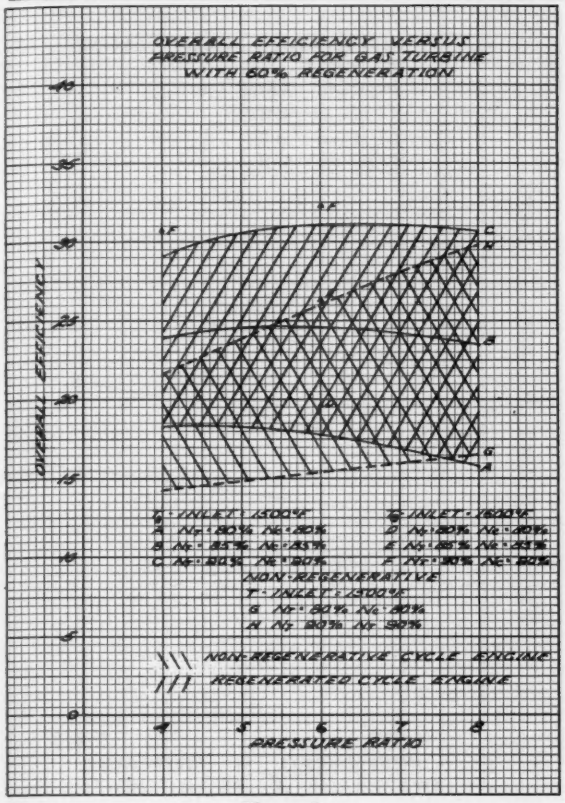


Figure 3.

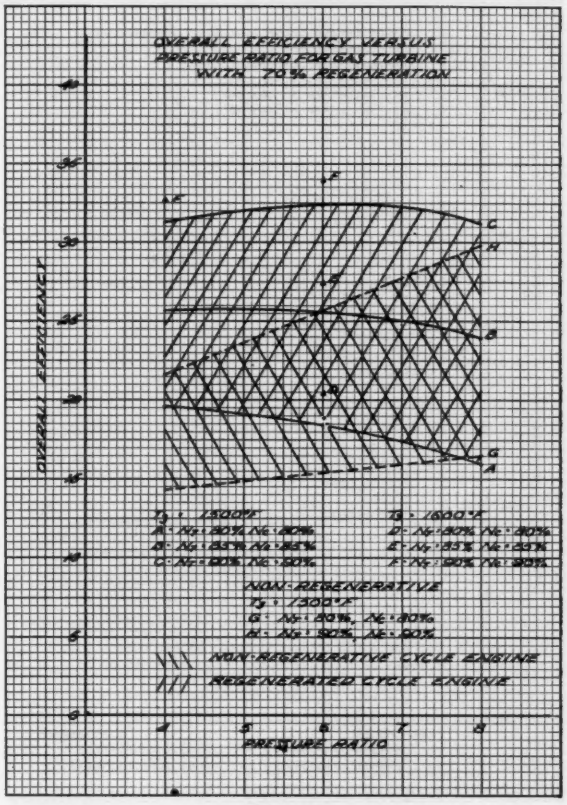


Figure 4.

gas will lower the specific fuel consumption, even though there is a noticeable loss in power output. Figures 3, 4 and 5 show the overall thermal efficiencies for regenerative cycles of 60, 70 and 80 per cent effectiveness respectively. These graphs also show a comparison of the regenerative cycle engine with that of a simple cycle engine. It can be noted that the level of component efficiencies has a major effect on overall efficiency. This is true for both the regenerative and simple cycle plants. As the pressure ratio increases it is noted that the gain in overall efficiency due to regeneration, decreases until the overall efficiency of the simple cycle engine will be greater than that for a regenerated engine. Furthermore, the higher the effectivenesss, the lower the optimum pressure ratio; the higher the level of component efficiencies, the higher the optimum pressure ratio.

It is also shown that regenerated engines are much more dependent on turbine inlet temperature for high overall efficiencies than non-regenerated engines. The regenerative cycle plant is very much dependent on the level of compressor and turbine discharge temperatures. Therefore, turbine inlet temperature has an appreciable effect on performance. Even with high efficiency components an appreciable increase in performance can be obtained by increasing the turbine inlet temperature. The increase is directly related to the effectiveness of the regenerator and is inversely related to the level of the component efficiencies.

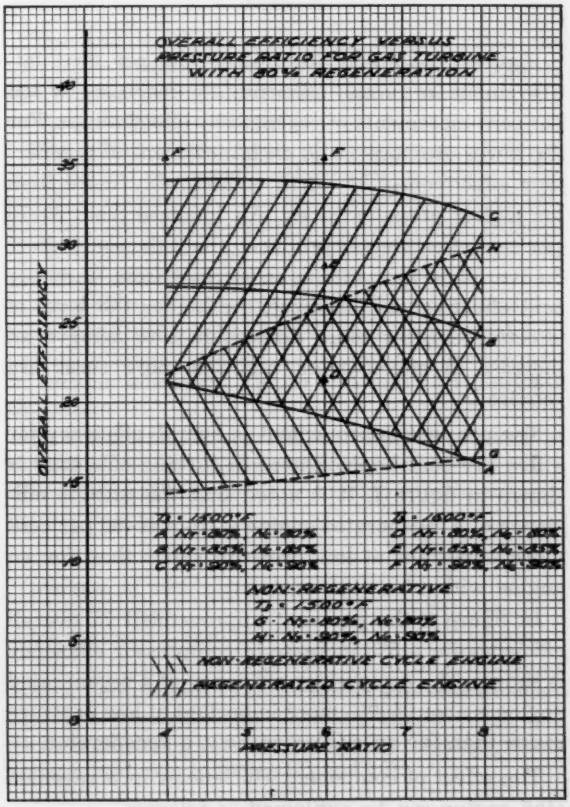


Figure 5.

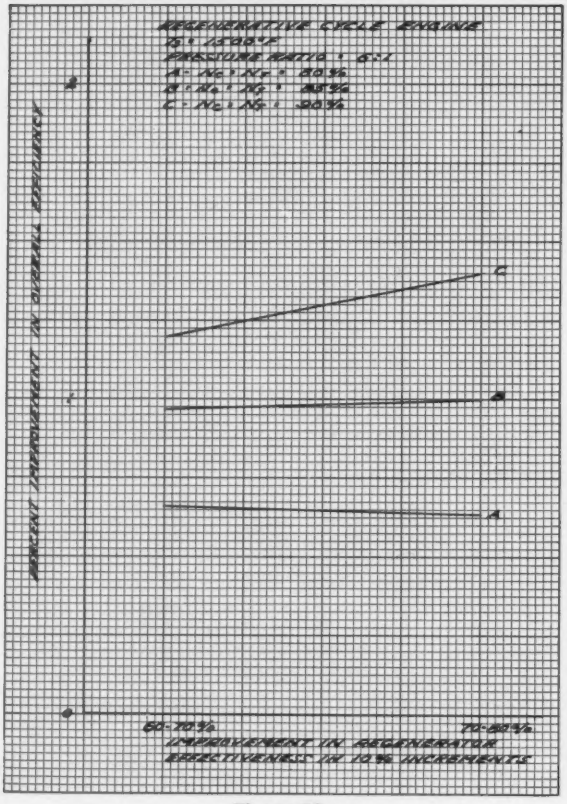


Figure 6A.

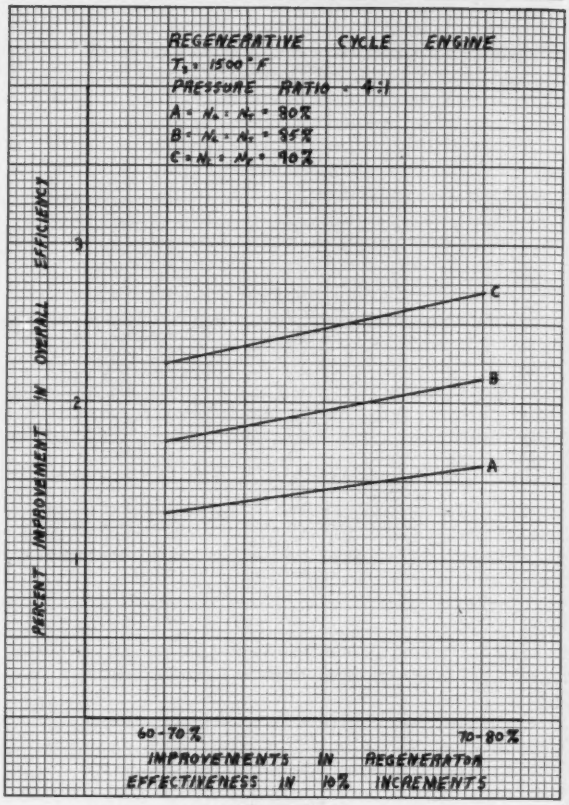


Figure 6B.

Figures (6)A and (6)B show the per cent improvement in overall efficiency for increases of ten per cent increments of regenerator effectiveness. For the lower pressure ratios each increment of regenerator effectiveness is worth considerably more than for higher pressure ratios. An increase from 60–70 per cent effectiveness produces about the same effect on overall performance as an increase from 70–80 per cent effectiveness; however, the higher the level of effectiveness, the more difficult it is to achieve an increase in effectiveness, and the more cores are required.

The per cent improvement in overall efficiency for a five per cent improvement in turbine efficiency is shown in figure 7. It is noted that the turbine efficiency of a regenerated engine is from 40–60 per cent more important at low pressure ratios than for an engine without a regenerator.

In figure 8 the per cent improvement in overall efficiency for a 5% increase in compressor efficiency is shown. The compressor efficiency of a regenerated engine is about 100% more important at low pressure ratios than for an engine without a regenerator.

The effect of component efficiencies in a regenerated engine can be explained as follows:

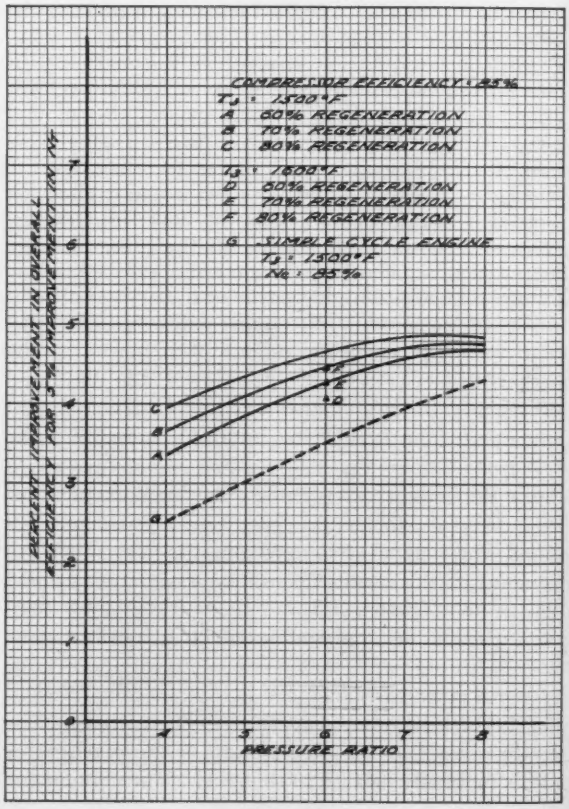


Figure 7.

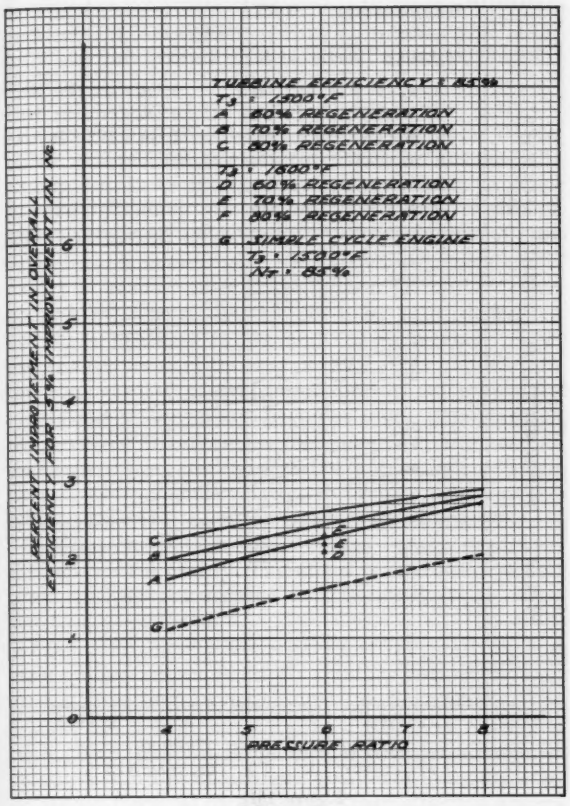


Figure 8.

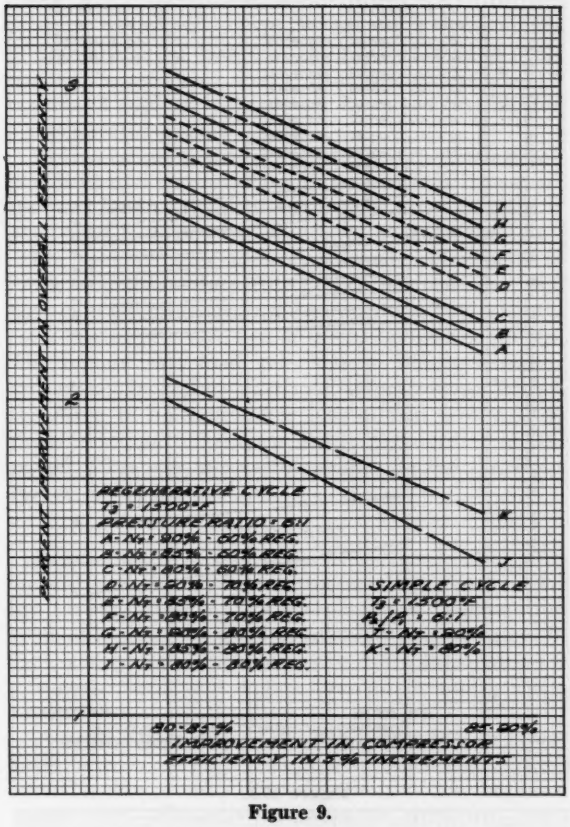

REGENERATIVE CYCLE
T3 = 1500°F
PRESSURE RATIO = 6:1
A - Nc = 90% - 60% REG.
B - Nc = 85% - 60% REG.
C - Nc = 80% - 60% REG.
D - Nc = 90% - 70% REG.
E - Nc = 85% - 70% REG.
F - Nc = 80% - 70% REG.
G - Nc = 90% - 80% REG.
H - Nc = 85% - 80% REG.
I - Nc = 80% - 80% REG.
SIMPLE CYCLE
T3 = 1500°F
PR = 6:1
J - Nc = 90%
K - Nc = 80%
80-85%
85-90%
IMPROVEMENT IN COMPRESSOR EFFICIENCY IN 5% INCREMENTS

Figure 9.

$$\text{Engine efficiency} = \left[\frac{N_t \times \triangle H_t}{\triangle H_{comb}}\right] - \left[\frac{\frac{\triangle H_c}{N_c}}{\triangle H_{comb}}\right]$$

Where:

N_t = Turbine efficiency
$\triangle H_t$ = Isentropic turbine work
$\triangle H_c$ = Isentropic compressor work
$\triangle H$ comb = Fuel energy added in combustor
N_c = Compressor efficiency

A. An increase in overall efficiency can be obtained by an increase in the ratio:

$$\frac{N_t \times \triangle H_t}{\triangle H_{comb}} = \frac{\text{Turbine work}}{\text{Fuel energy required}}$$

The amount of fuel energy required is dependent on the temperature at the regenerator discharge. The higher the effectiveness, the higher the regenerator discharge temperature and the smaller the fuel energy required.

The smaller the denominator in the above ratio the more effect each increment of turbine efficiency has on increasing the overall ratio and therefore overall efficiency.

B. An increase in overall efficiency can be obtained by a decrease in the ratio:

$$\frac{\frac{\triangle H_c}{N_c}}{\triangle H_{comb}} = \frac{\text{Compressor work}}{\text{Fuel energy required}}$$

The smaller the denominator in this ratio, the more effect each increment of compressor efficiency has on decreasing the overall ratio; therefore, the overall efficiency increases.

The effect of the level of compressor efficiency with respect to overall performance is shown in figure 9. It emphasizes that for higher compressor efficiencies, each additional unit of compressor efficiency has less effect on overall efficiency, than the previous unit of compressor efficiency.

For different levels of turbine efficiency there is a very small differential in per cent improvement in overall efficiency for an increment of improvement in turbine efficiency. Figure 10A and 10B illustrate this effect.

In comparing figures 6B and 10B the levels of overall efficiency improvement due to increments of regenerator effectiveness or turbine component performance are:

	Increase in overall efficiency
Increase of 10% regenerator effectiveness	2% approx.
Increase of 5% turbine efficiency	3.7% approx.

An increase of five per cent in turbine efficiency is about equivalent to 20% regenerator effectiveness. The exact relationship between effectiveness and turbine efficiency is a function of the thermodynamic regime as shown in figure 6B and 10B.

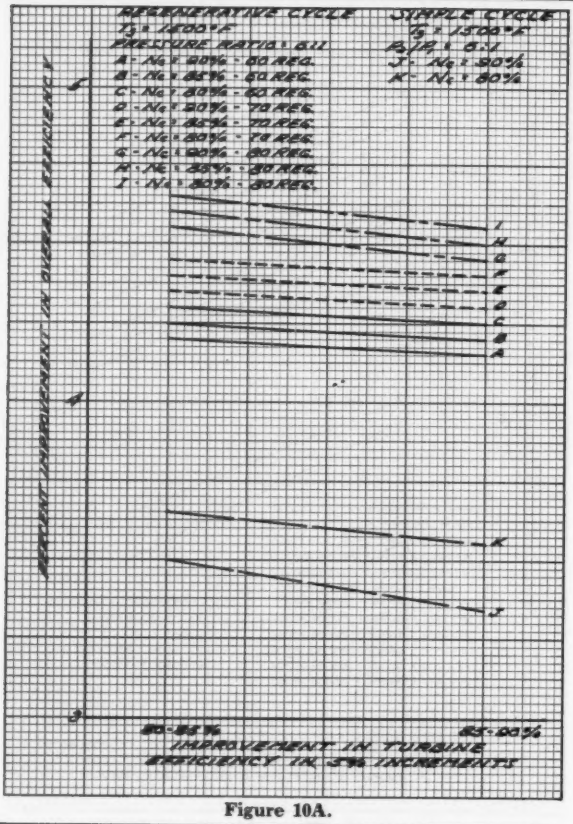

REGENERATIVE CYCLE
T_3 = 1600°F
PRESSURE RATIO = 4:1
A - N_R = 90% - 60 REG.
B - N_R = 85% - 60 REG.
C - N_R = 80% - 60 REG.
D - N_R = 90% - 70 REG.
E - N_R = 85% - 70 REG.
F - N_R = 80% - 70 REG.
G - N_R = 90% - 80 REG.
H - N_R = 85% - 80 REG.
I - N_R = 80% - 80 REG.
SIMPLE CYCLE
T_3 = 1500°F
P_2/P_1 = 4:1
J - N_R = 80%
K - N_R = 80%
RELATIVE IMPROVEMENT IN OVERALL EFFICIENCY
80-85%
85-90%
IMPROVEMENT IN TURBINE EFFICIENCY IN 5% INCREMENTS

Figure 10A.

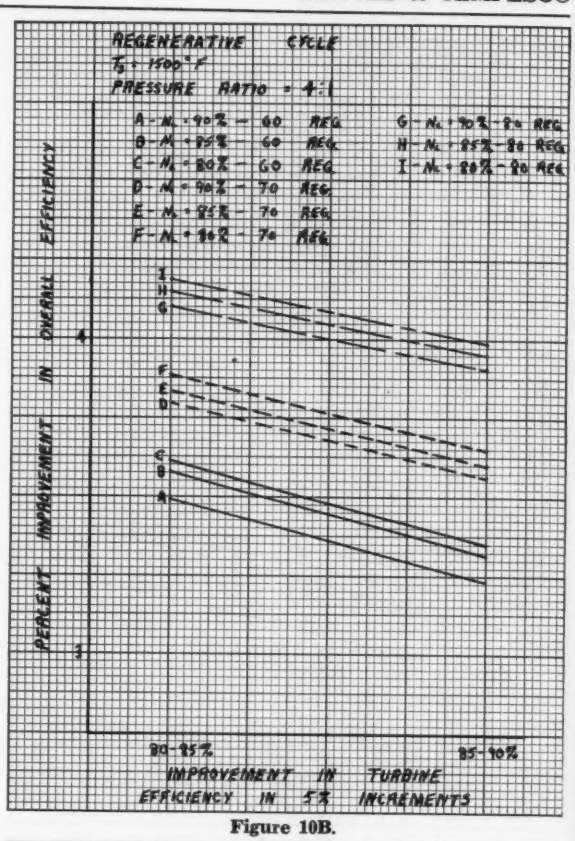

REGENERATIVE CYCLE
T_3 = 1500°F
PRESSURE RATIO = 4:1
A - N_c = 90% - 60 REG
B - N_c = 85% - 60 REG
C - N_c = 80% - 60 REG
D - N_c = 90% - 70 REG
E - N_c = 85% - 70 REG
F - N_c = 80% - 70 REG
G - N_c = 90% - 80 REG
H - N_c = 85% - 80 REG
I - N_c = 80% - 80 REG
PERCENT IMPROVEMENT IN OVERALL EFFICIENCY
80-85%
85-90%
IMPROVEMENT IN TURBINE EFFICIENCY IN 5% INCREMENTS

Figure 10B.

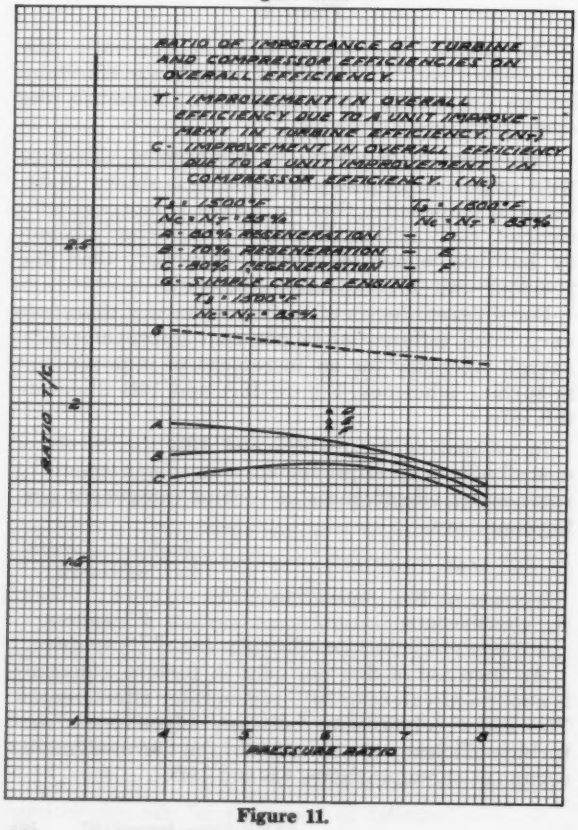

RATIO OF IMPORTANCE OF TURBINE AND COMPRESSOR EFFICIENCIES ON OVERALL EFFICIENCY.
T - IMPROVEMENT IN OVERALL EFFICIENCY DUE TO A UNIT IMPROVEMENT IN TURBINE EFFICIENCY. (N_T)
C - IMPROVEMENT IN OVERALL EFFICIENCY DUE TO A UNIT IMPROVEMENT IN COMPRESSOR EFFICIENCY. (N_C)
T_3 = 1500°F
$N_C = N_T$ = 85%
A - 80% REGENERATION = D
B - 70% REGENERATION = E
C - 60% REGENERATION = F
G - SIMPLE CYCLE ENGINE
T_3 = 1500°F
$N_C = N_T$ = 85%
T_3 = 1600°F
$N_C = N_T$ = 85%
RATIO T/C
PRESSURE RATIO

Figure 11.

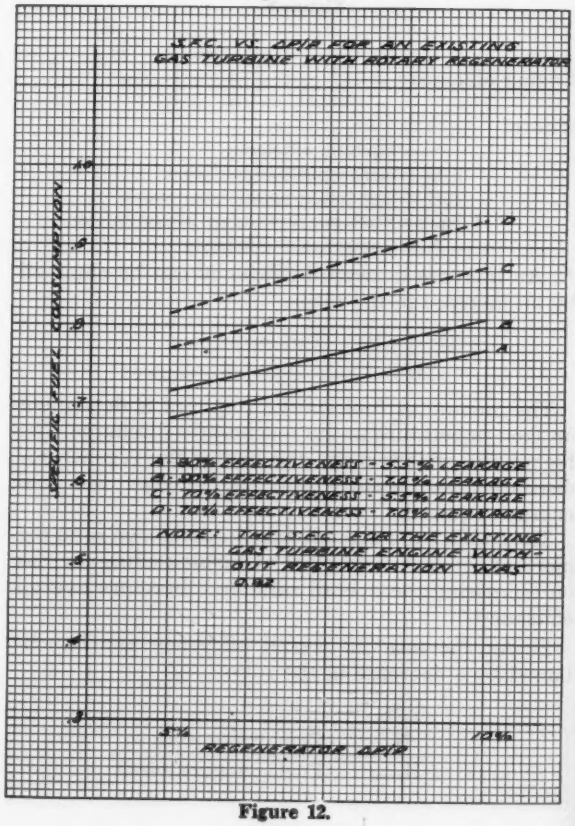

SFC VS. ΔP/P FOR AN EXISTING GAS TURBINE WITH ROTARY REGENERATOR
SPECIFIC FUEL CONSUMPTION
A: 80% EFFECTIVENESS - 3.5% LEAKAGE
B: 80% EFFECTIVENESS - 7.0% LEAKAGE
C: 70% EFFECTIVENESS - 3.5% LEAKAGE
D: 70% EFFECTIVENESS - 7.0% LEAKAGE
NOTE: THE SFC FOR THE EXISTING GAS TURBINE ENGINE WITHOUT REGENERATION WAS 0.382
3%
10%
REGENERATOR ΔP/P

Figure 12.

A plot of the relative ratio of importance of turbine and compressor efficiencies on overall efficiency is shown in figure 11. This ratio is defined as the per cent improvement in overall efficiency due to an increment of improvement in turbine efficiency (5 per cent) divided by the improvement in overall efficiency due to an increment of improvement in compressor efficiency (5 per cent). For the region of high component efficiencies, the importance ratio of turbine and compressor efficiencies on overall efficiency is greater than at the region of the low component efficiencies. The importance ratio decreases at higher pressure ratios, and varies inversely with the effectiveness of the regenerator. This implies that the importance of compressor performance relative to turbine performance becomes more important as the level of effectiveness increases. For the case of the non-regenerated engine the importance of compressor performance relative to turbine performance is less important than for a regenerated engine.

Light weight, high effectiveness rotary regenerators are now a reality. The effect of seal leakage and pressure losses associated with a rotary regenerator must be considered.

Figure 12 illustrates the effect of the pressure and leakage loss associated with a rotary regenerator on an existing engine (calculated performance). The engine has a pressure ratio of 5 to 1 and a specific fuel consumption of .92 pounds of fuel per horsepower hour. In order to achieve a reduction in fuel consumption from .92 to .7 a 90 per cent effective regenerator with leakage and pressure losses less than 5 per cent are required. The power output rating would be decreased by at least 30 per cent. The future of rotary regenerators is dependent on programs aimed at reducing pressure and seal leakage losses.

Rather than modify an existing engine it is considered preferable to consider the use of simple low pressure ratio turbine and compressor components of high efficiency. Based on the present level of component "know how" fuel consumptions less than .5 pounds of fuel per horsepower hour are feasible for a regenerated engine.

Regenerators provide a method of reducing the part load fuel consumption of gas turbines; however, the part load component efficiencies must be good if good part load performance is to be achieved.

For specific cases where part load performance is more important than full power performance, the part load effectiveness can be improved by designing for a higher pressure loss at the full power condition. The higher part load velocities in the regenerator will result in higher part load effectiveness. An alternative to high pressure loss at full power is to provide for partial bypass of the regenerator at full power. This was successfully done on the the Rolls Royce RM60 gas turbine.

CONCLUSION

Regenerators of moderate effectiveness offer considerable theoretical performance improvement for gas turbine engines. The complexity of regeneration is no substitute for good component performance. In fact, component efficiencies are more important for a regenerated cycle engine than for a simple cycle engine.

A regenerated engine designed for a low pressure ratio and with high component efficiencies offers considerable promise. The simplicity of low pressure ratio, high efficiency components combined with moderate effectiveness regenerators offers a simple, high performance plant. Special emphasis must be devoted to duct arrangements and pressure losses.

ACKNOWLEDGEMENT

Figure 12 was prepared by Mr. Charles Miller of the Bureau of Ships, Gas Turbine Branch.

The National Bureau of Standards has recently developed improved techniques for producing precise etched glass scales. These techniques can be used for high-precision graduated glass circles and reticules for theodolites and glass scales for various optical measuring instruments.

TURBINE BLADE VIBRATION

ACKNOWLEDGEMENT

This reprint consists of two separate articles published in "Engineering." Part I, published in the August 17, 1956, edition, was written by F. Andrews, of the British Electrical Engineering Co., Ltd., and J. P. Duncan, a lecturer at the University of Manchester. G. A. Luck, of Fraser and Chalmers Engineering Works, and R. C. Kell, of the General Electric Company Research Laboratories at Wembley, Middlesex, are the authors of Part II, which was published in the August 31, 1956, edition.

I—MEASURING EQUIPMENT DEVELOPED BY BRUSH

ALTHOUGH TURBINE BLADES are proportioned in the first instance from thermodynamic considerations, their dynamic characteristics in respect to all possible modes of vibration are of great concern to designers. The danger of resonances of blades or blade-packets in working machines and the consequential failure due to fatigue is too well known to require amplification. The present trend towards ever increasing capacity and reliability of turbo-generators has necessitated the development of suitable equipment to ensure that dangerous resonant conditions are avoided. Demands for expanding production and for the shortening of manufacturing time also require that any test or investigation shall be made with minimum extension of delivery dates.

In the following account of methods and equipment developed by Brush Electrical Engineering Company, Limited, Loughborough, equipment is described for recording the behavior of blades assembled in turbine rotors when these are rotating in vacuum, and for preparatory static tests to determine the degree of tuning possible by various methods. The rotational tests are based on the electrical resistance strain gauge technique which can be applied to both steam and gas turbines, and has the advantage that with suitable development it is applicable to blading operating under normal working conditions.

CALCULATION OF FREQUENCIES

To examine theoretically the problem introduced above, the modes and natural frequencies of blades and blade assemblies must be known, together with the frequencies of all sources of excitation. The natural frequencies present the most difficult problems, since blade systems consist of continuous elements of stiffness and inertia. The modes and nodal shapes are therefore difficult to predict. Further, the degree of fixation provided by mechanical blade-root attachments is often indefinite and dependent on shop procedure. Finally, centrifugal force acting on the blades of an assembled rotor under working conditions will affect both the stiffness of the vibrating elements and the degree of root-fixity.

It is usual to base a design method on a single blade fixed as a cantilever, as shown in Fig. 1. Where the blade is of uniform cross section from root to tip it is comparatively simple to calculate approximately the natural frequency of the first mode by assuming a shape for the neutral axis during vibration. The precise calculation is far more laborious and requires a knowledge of the exact shape of the dynamic deflection curve. The single blade will have its lowest mode and frequency when vibrating in the plane xx with which will be associated harmonic modes. Another series of modes will be associated with plane yy and a third with torsional vibration about O. Tapered blades introduce further complications to the above calculations.

When assembled in packets, blades are generally

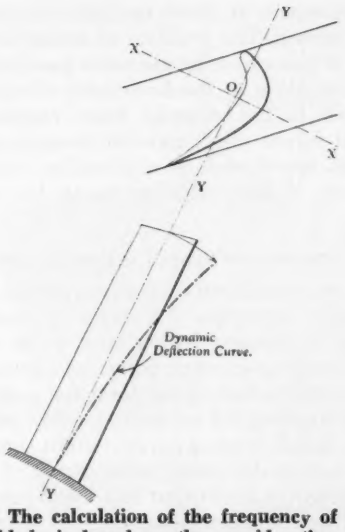


Figure 1. The calculation of the frequency of vibration of a turbine blade is based on the consideration of a simple cantilever.

tied together by intermediate wire lacings or by shrouding. It has been found that a group of blades so arranged exhibit the three principal modes of vibration, of the form shown in Fig. 2. More complicated modes are possible but these have been found to be of less importance. Existing methods of design endeavor to relate the behavior of single blades to that of packets. The effect of shrouds in stiffening and adding mass to packets and the indefinite end-fixity which they afford will be obvious. In addition, an allowance must be made for all the likely effects of rotation.

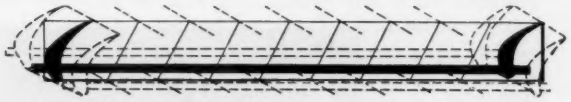
BLADE FREQUENCIES BY EXPERIMENT

It is customary to make physical tests on stationary blades and stationary packets of blades to confirm or supplement calculations. Separate blade tests are conducted in order to find natural modes and frequencies which are important for confirming calculations and also to determine endurance limits for blade materials and blade designs. Tests on blade packets are usually designed to find the modes and frequencies which may be excited in actual machines and to experiment with means of altering natural frequencies to avoid known excitation frequencies. The principal means used is the fitting of lacing wires and damping wires as described later. Tests on packets may be performed on a stationary rotor to which packets have been mounted by a standard production method or, during development, on a bench clamping fixture. While such tests go a long way towards resolving the difficulties of calculation, they still fail to deal with the effects of rotation.

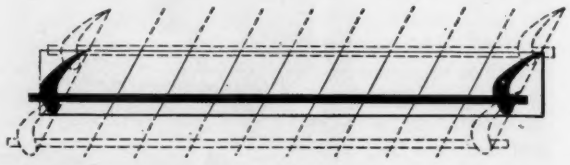
It would appear to be a desirable objective, therefore, to measure blade vibration on assembled turbine rotors while in normal operation. General studies of this nature could be performed on a specially designed turbine but it is unlikely that such a machine should become available. On the other hand, with suitable recording equipment the behavior of blade assemblies in working production machines might be observed and the results compared with present design practices. With equipment described below, production rotors rotating in vacuum have been tested. At the same time, refinements in apparatus and the development of high temperature and waterproof electric resistance strain gauges are proceeding towards the desirable objective of testing gas and steam turbines under load.

LJUNGSTROM TURBINES

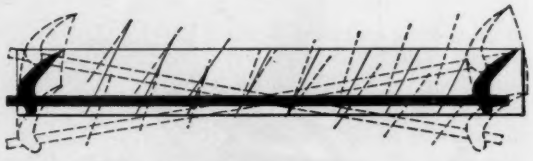
The general construction of the Ljungstrom radial flow turbine is too well known to require detailed explanation. A typical impression of the rotor of such a machine will be found in Fig. 8. The two rotors of the machine, referred to as "ordinary end" and "governor end" are counter rotating, each actuating an alternator. Each turbine rotor is overhung from its associated electrical rotor, so that blade rings of one interleave with blade rings of the other. Steam introduced to the center of the machine flows radially outwards in a steam space sealed by radial labyrinth glands. It first passes through a series of "inner blade-rings." These consist of blades cut from machined or extruded strip welded into dovetail section rings. This assembly is then rolled at each end into strengthening rings. The strengthening ring nearest to the disc which supports it is rolled on to the well-known dumb-bell section expansion ring which is in



(a) Major Batch Mode.
Bending About Axis of Minimum Moment of Inertia



(b) Minor Batch Mode
Bending About Axis of Maximum Moment of Inertia



(c) First Torsional Batch Mode
Individual Blades Vibrating in the Fundamental Cantilever Mode

Figure 2. Diagram of the principal modes of packet vibration.

turn rolled into a rectangular-section seating ring. This is caulked into a circumferential groove in the side of the turbine disc by means of a square-section wire.

Beyond a certain radius, welded construction can no longer be used owing to increased stresses. A different type of construction is therefore adopted for the outer rings in which blades milled from the solid with integral roots are fixed at their ends in dovetail section grooves milled on the inner faces of strengthening rings. The steam after leaving the radial flow portion of the blading is deflected through one or more stages of axial flow blading in the larger sizes of turbines and then flows downwards to the exhaust opening in the casing. These latter stages are similar to those encountered in conventional axial flow machines, the blades being attached to the periphery of the discs by means of de Laval or circumferential fir-tree root fixings.

The elements most sensitive to dangerous vibration are the blade rings and the blade packets of the axial flow stages; the extreme rigidity of both discs and radial flow blades excludes their modes from excitation by any but weak higher harmonics.

Excitation frequencies have been found by experience to be harmonically related to the rotational frequency of the turbine. Mainly they are due to deviations from radial and circumferential symmetry of the pressure distribution through the axial and radial flow blading respectively.

The frequencies at which excitation is possible are therefore known. The problem of design is to ensure that none of the vibrating elements have natural frequencies too close to the harmonics of normal running speed. It has already been mentioned that centrifugal forces affect natural frequencies. These frequencies are therefore required as functions of rotor r.p.m. if the situation is to be accurately assessed.

STATIC TESTING OF BLADES, PACKETS AND RINGS

Fig. 3 is a reproduction of a photograph of equipment used at Brush for the study of single blades. The blade is clamped by its root to an anvil and excited by a direct-current polarized electro-magnet. Various modes including the torsional mode may be excited by locating the magnet suitably and supplying it with an alternating current input signal having the frequency of the mode under study. A precision oscillator controls the output of a 1 kW power amplifier supplying the electromagnet.

Although this equipment is employed for finding the natural frequencies of a blade it is used principally for fatigue testing. The endurance limit of a new blade design, the variability of production batches or the suitability of blades which are not strictly to drawing can all be investigated by means of comparative tests. For this purpose after the blading has been brought into resonance in the particular mode required, circuits in the fatigue control unit

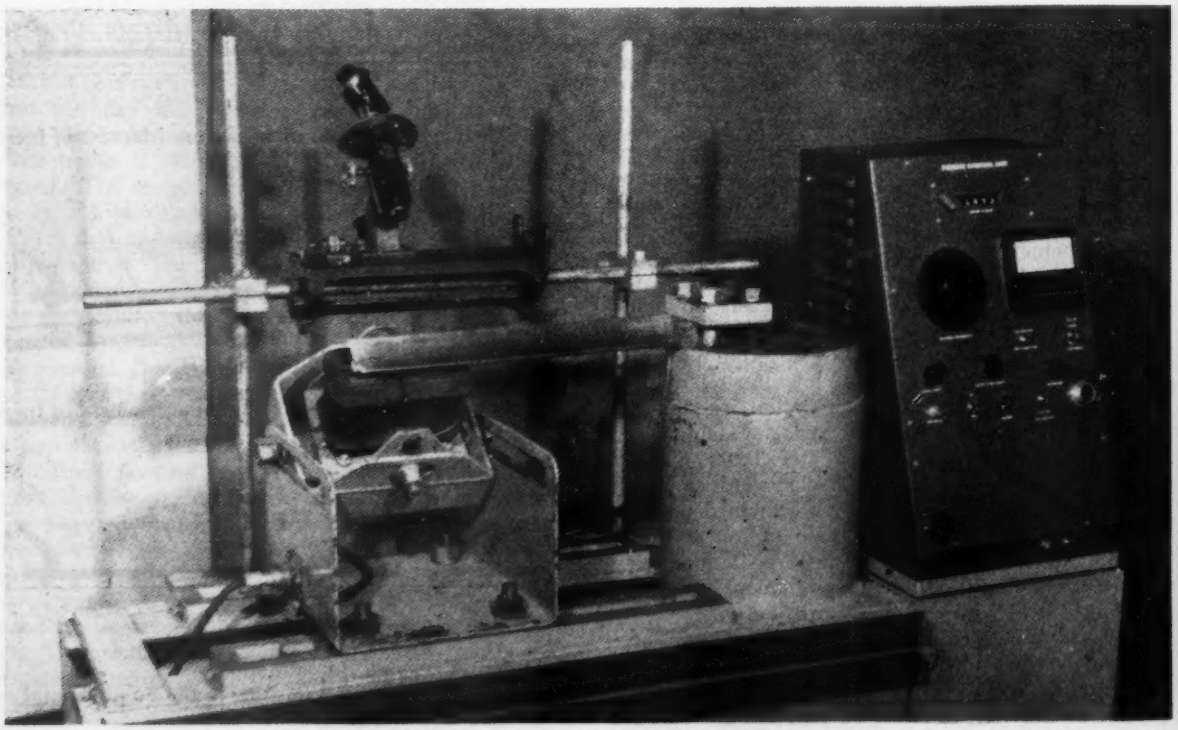


Figure 3. Test rig for determining the natural frequency of a single blade. By illuminating the vibrating blade with a stroboflash, the microscope can be used to determine the dynamic deflection curves.

Figure 4. The natural frequency of a blade depends considerably on the form of root-fixation and a blade packet can be examined on a bench fixture.

are used to control, by feed back from the blade under test, the power amplifier output. The fatigue control unit includes a bank of "decatron" counting tubes which accurately cover every 1,000 oscillations of the blade, regarding this number as a unit on a magnetically operated mechanical counter. With the onset of fatigue-cracks and even before these can be detected by eye, the frequency of blade and exciter will fall due to reduced blade stiffness. A further circuit incorporated in the fatigue control switches

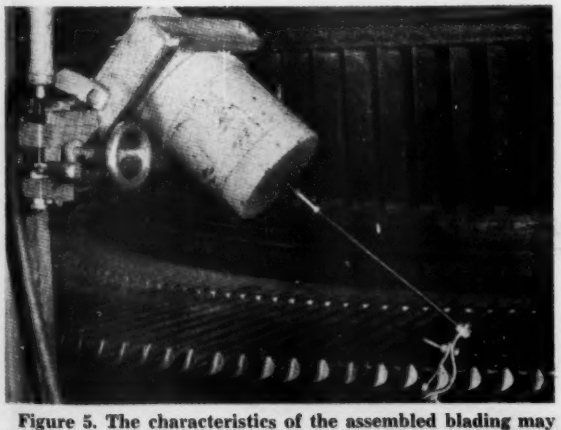


Figure 5. The characteristics of the assembled blading may also be determined. Both moving-coil and electro-magnetic exciters are used to generate vibrations in these tests.

off the power amplifier when the frequency falls by 2 per cent. This fixes a definite end-point to the fatigue test. The test may subsequently be extended until visible cracks and even failures occur, thus revealing sections of weakness.

The free end of a vibrating blade can be revealed by suitable illumination. The plane of vibration which will be normal to the axis of least second moment of area of the section is clearly seen. By setting the microscope normal to this plane and illuminating the vibrating blade by stroboflash the amplitude at any position along the blade may be observed. The microscope can be traversed on its transverse slide over the length of the blade. By moving it in turn to a number of stations along the blade-length the shapes of the dynamic deflection curves may be determined. These accurately reveal the modes of vibration and assist in calculating the natural frequencies of new blades of similar design.

Packets of blades are tested when mounted on a bench fixture as in Fig. 4 or after assembly to the rotor discs as in Fig. 5. Tests in the bench fixture are designed to find and, if necessary, modify the natural frequency of packets. Both moving coil and electromagnetic exciters are used in these tests. A crystal exciter has also been manufacturd to investigate short blades of high natural frequency and has the advantage of low power consumption. The modes of packet vibration which normally require investigation are depicted in Fig. 2. These, and more complex modes, can be excited by a suitable location of the exciter; the phase and amplitude being explored by means of a probe attached to a microphone element. The method of detection is well known. In initial tests blades are provided with a number of holes as shown. A preliminary test suffices to find the natural frequencies of the packet. Should these be unsuitable monel tubes or steel wires may be threaded through the holes provided to effect changes. These tubes or steel wires may be brazed to the blades or be friction fits. In the first case they effect a change of stiffness and are called "lacing wires"; in the second they cause damping and are referred to as "damping wires." The tubes may also be crimped between the blades. This provides a ready means of adjusting their bending stiffness and consequently their effect on the natural frequency of the packet.

ROTATION EFFECTS ON BLADES

When blade packets are assembled on a rotor by a standard production method, it is found that appreciable variation in root fixity gives rise to variations in the natural frequencies from packet to packet round a complete row. Further changes in natural frequency are known to take place as the rotor rotates. These changes are partly due to the stiffening effect of centrifugal force and also to variations in root fixity. Under these circumstances successive packets round a wheel will interchange their energy through coupling effects and the behavior of the

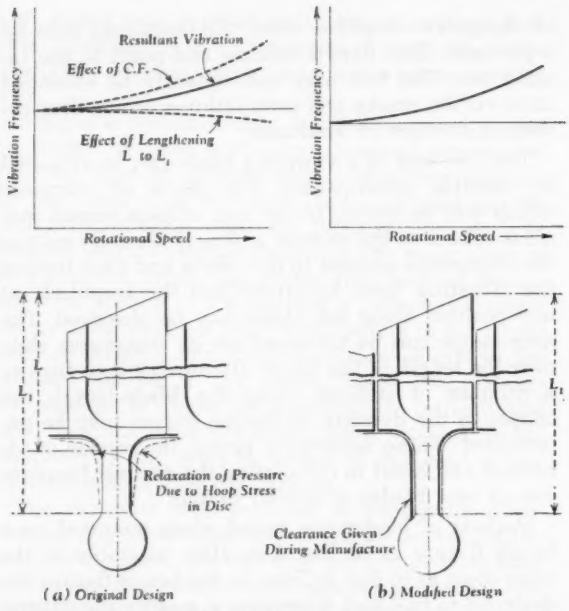


Figure 6. Diagrams showing the effects of changes in blade fixing designed to reduce frequency scatter.

wheel may be more complicated than appears at first sight.

To illustrate the effect of rotation on root fixity the de Laval blade-root, fitted to an axial slot, may be quoted. This is illustrated in Fig. 6. As formerly used, this root was a tight fit in the bulb and a light push fit in the slot. At speed the slot opened out as shown dotted, increasing the effective length of the blade subject to vibration and altering the natural frequency from that observed in static tests (quite apart from the stiffening effect of centrifugal force). The problem was solved by giving the neck and shoulder of the blade adequate clearance so that the blade was effectively fixed at the bulb, whether stationary or rotating. Where stresses warrant the expense of the "fir tree" type of fixing, the de Laval root is now being superseded by this type.

OBSERVATION ON ROTORS

Sufficient has been said to make clear the desirability of observing the vibration of blading components in working machines. Three principal difficulties stand in the way of such a procedure, but none of these are insurmountable. Compact lightweight moisture-proof sensitive elements or pick-ups capable of working at moderately high temperatures are required at the component surfaces. Electrical leads must have access from the elements through the rotor to the frame of the machine. The signals from the sensitive elements must be faithfully transmitted to recording equipment.

An obvious choice of sensitive element is the electrical resistance strain gauge. Brush are currently investigating various types of gauges and suitable fixing techniques, but this work is still in a development stage. New methods of moisture proofing are also being examined and some of these have been applied in tests conducted in an evacuated air space as described below. In these tests a steam seal is used and the gauges and leads are exposed to water vapor and danger of short circuiting.

The gauges must be attached to axial flow blades near their roots or to strengthening rings and electrical leads must be conducted down the rotor to a slip-ring unit, as in Fig. 7 (*a*) and (*b*). The construction of a Ljungstrom turbine makes this even more difficult than would be the case for a pure axial-flow turbine.

At the present time no working turbine has been so wired, but rotors from actual machines have been wired, as is shown in Fig. 8, the rotor being overhung in an evacuated chamber through a steam-sealed gland. The radial labyrinth gland rings on the rotor and radial flow blade rings are not engaged with their counterpart in these tests. Hence the leads from the gauges can be cemented across these labyrinth strips or blade rings and led along the shaft to a slip-ring unit as shown in Fig. 7 (*a*.)

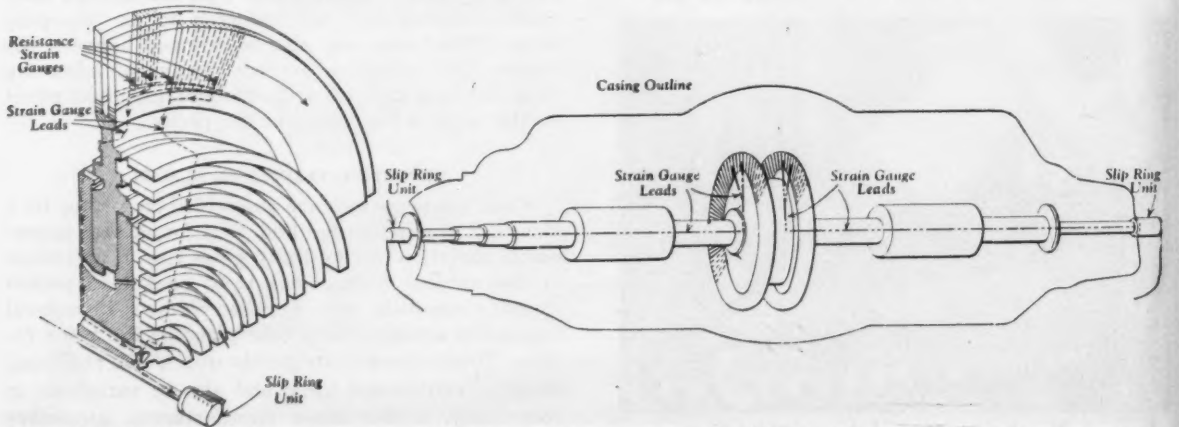


Figure 7. Electrical resistance strain gauges have been used to determine the vibration characteristics of the blades under working conditions. Diagram (a) shows the positions of the strain gauges and the leads from the 1st and 2nd stage blading to the slip-ring unit. Diagram (b) shows the routes of the leads from the gauges in a working machine.

The remaining problem is to choose a circuit in which to incorporate the detecting strain gauge. It must also be decided whether both the steady and alternating components of strain or just the alternating components are to be measured; whether both amplitude and frequency or just frequency are to be found. This hinges on the relative advantages and disadvantages of alternating-current or direct-current circuits and on the effects of capacitance leakage to earth from long flexible leads.

In the system to be described the relative magnitude of the alternating-current output signal from the potentiometer circuit is used to indicate the onset of resonance. A calibration is made, if necessary, to determine absolute amplitudes, but the frequency of the signal is the factor of primary interest and this can readily be found by comparison with a precision oscillator.

To transfer signals from rotating to stationary member an efficient slip ring unit is necessary. It has nine silver palladium rings of ⅜ in. diameter by ⅛ in. width, the brushes—two to each ring—being of 80/20 silver graphite by weight. In tests on steam turbine blading maximum speeds of 3,600 r.p.m. are attained, the noise level being extremely low. For tests made on gas turbines and turbo-blowers, successful operation up to 15,000 r.p.m. has been attained and further developments are in progress to extend the range to 30,000 r.p.m. Incorporated in this slip ring unit is a 30 toothed tachometer head which, used in conjunction with an electronic tachometer, makes possible the measurement of speed up to 10,000 r.p.m. with an accuracy of ± 1 r.p.m. The range may be extended to cover 100,000 r.p.m. with a corresponding accuracy of ± 10 r.p.m.

Since it will be necessary to observe each of a large number of gauges with equipment capable of handling only a limited number of simultaneous signals, some form of switching is required. A relay selector unit is therefore mounted on the rotating member to perform this function before the signals reach the slip rings. This relay switches groups of three gauges from a maximum of 24 and feeds out their signals simultaneously.

MOBILE RECORDING

With a view to pursuing the line of investigations outlined above, a mobile recording unit has been built. The instruments required for selecting, recording and analyzing the strain-gauge signals received through the slip-rings have been built into a trailer. The unit can handle three simultaneous signals from any three of 24 strain gauges or signals from displacement-type pick-ups; this facility may be useful for special investigations. The signals are monitored visually on two double-beam oscilloscope screens and recorded on magnetic tape. In addition a very accurate tachometer takes a periodic count of revolutions per minute. The operator may also issue instructions, make comments and note recorded speeds by making an audible announcement which is also transferred to the magnetic tape.

At the completion of the test run, the magnetic tape retains a complete record of the behavior of any selected axial-flow blade packet or blade ring. The tape may then be played back into an oscilloscope and photographed by means of the moving film camera. The record can then be transferred to a white print, giving a record of vibrational strain against rotational speed; Fig. 9 shows typical records placed against a corresponding frequency/speed

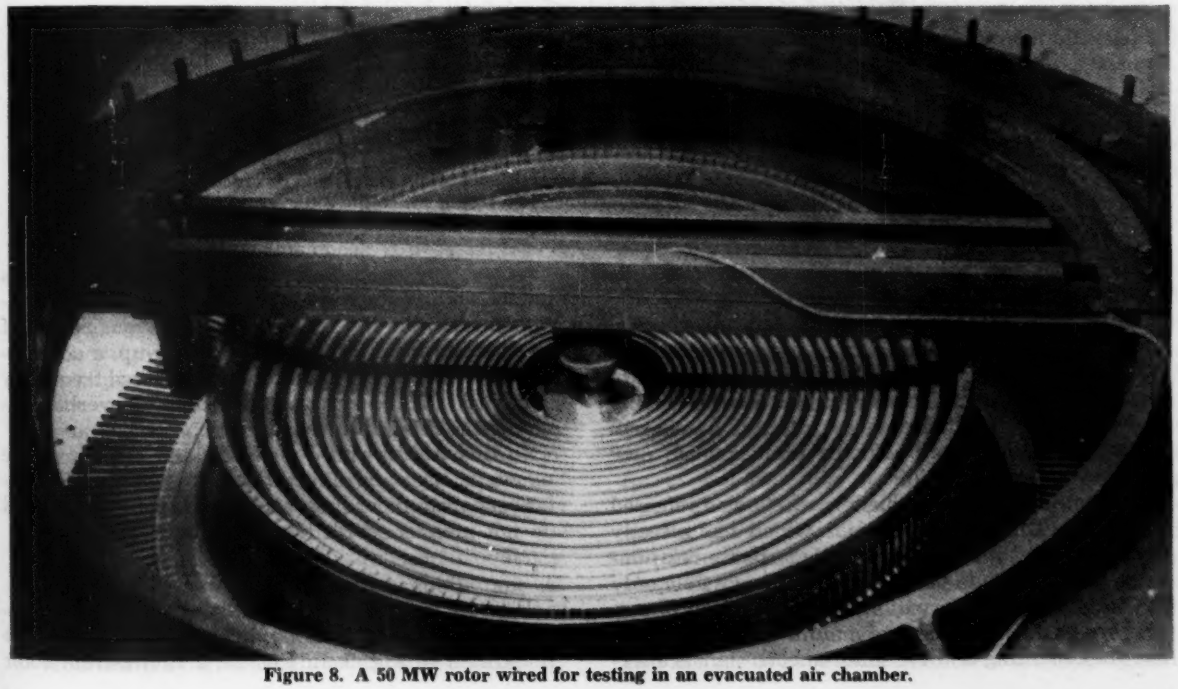


Figure 8. A 50 MW rotor wired for testing in an evacuated air chamber.

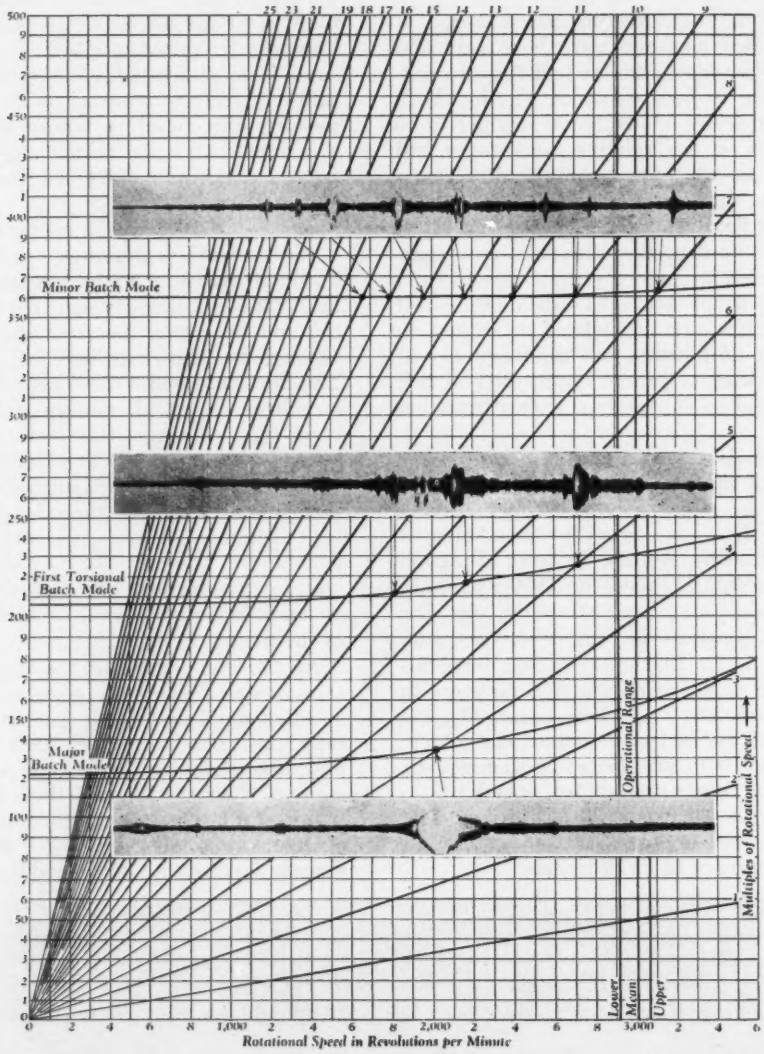


Figure 9. Blade response, as measured by resistance strain gauges and recorded on a moving film. The data were determined in a test in which the rotor was run up to its operational speed.

graph which has been compiled from the magnetic tape recordings.

Until recently, the unit operated on one channel only but it has now been extended to operate on three channels simultaneously. This has reduced to less than one-third the time required for the blading to be available for the determination of its characteristics. Further, more complex problems can now be investigated.

The coupling between blade packets was referred to earlier. To explain behavior which has already been described it is essential to study phase relationships between blade packets and this is possible only by simultaneous observation of the vibration of two or more packets by means of a multi-channel system. For the recording of these simultaneous signals a six-channel tape recorder is used which has six heads in line on a ½ in. wide tape. As well as three vibration signals, the tape receives a continuous record of shaft speed from the tachometer pick-up, a continuous reference frequency from a calibrated frequency standard and a separate recording of verbal announcements as mentioned above.

In this way errors due to slip and stretch of the magnetic tape and difficulties of synchronizing several separate recording machines are eliminated and do not interfere with the subsequent analysis.

RECORDING CIRCUIT

Fig. 10 shows diagrammatically a basic single-channel system used to obtain a record of the type illustrated in Fig. 9. In Fig. 10, a Ljungstrom rotor

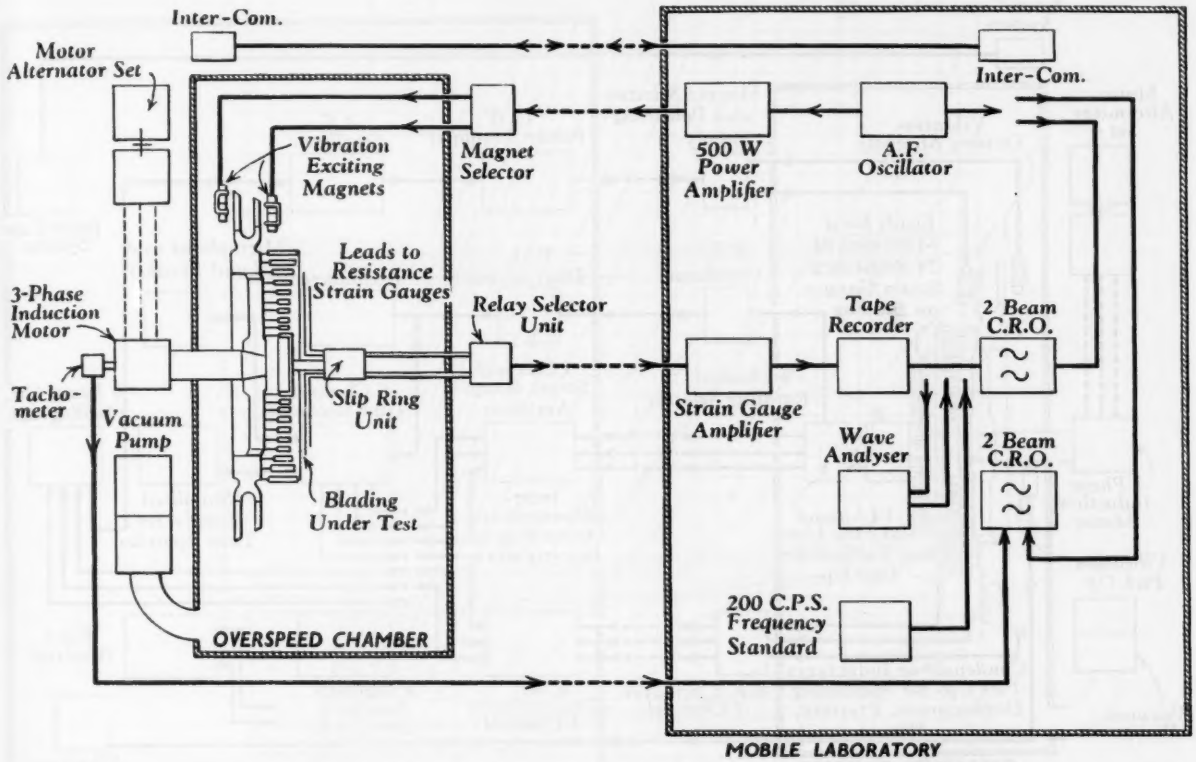


Figure 10. Diagrammatic arrangement of apparatus required for the dynamic testing of blading of a working turbine, using a single-channel strain-gauge system.

is indicated as being overhung into an evacuated chamber.

Although there is sufficient inherent excitation to promote vibration during rotation of the rotor due to minute unbalance forces in a nominally balanced rotor, it is necessary to excite the discs and blade rings at a few arbitrary speeds in order to prevent any ambiguity arising as to the identity of the characteristics of the various modes of vibration. The electro-magnets shown are used for this purpose and also for checking the frequency of vibration when the rotor is stationary. This check is necessary as it is found that variations in frequency occur due to the blades settling down in their supporting members with slightly different positions after running at high speeds.

An important component of the circuit, which is largely self-explanatory in other respects, is the wave analyzer—a Muirhead-Pametrada unit. It may be tuned to a variable bandwidth thus avoiding violent fluctuations in the signal at a selected resonant frequency when conditions are not absolutely steady or when one blade packet may be forcing the one under observation at a slightly different frequency. It is used when playing back the magnetic tape recordings of strain gauge signals if only a selected portion of the vibration spectrum is being scrutinized or recorded photographically as explained later.

In its complete form the system is as in Fig. 11. Extra channels have been added for both excitation and detection, the latter providing the added facility of a frequency-modulated carrier type multi-channel system for measuring displacement and pressures. The instrumentation can thus be applied to investigations outside the vibration field. It will also be noted that the tachometer head has been combined with the slip-ring elements, giving a compact unit which is readily demountable after testing.

SPEED CHARACTERISTICS

Fig. 12 shows a typical record of the characteristics for a complete stage of axial-flow blading as compiled from test data. The harmonics of running speed are shown as straight lines radiating from the origin. The packet frequencies at rest of the three principal modes shown in Fig. 2 are known from static tests or can be found at the commencement of a rotational test in the chamber. The net effect of centrifugal forces will generally produce characteristics which rise with rotor speed as shown. Each characteristic is shown as a band which covers conditions of full and partial resonance for all blade packets in a particular stage. It is compiled from a series of individual blade packet responses similar to that shown in Fig. 2. Blade packets to which strain gauges are attached, and as a result have their characteristics investigated,

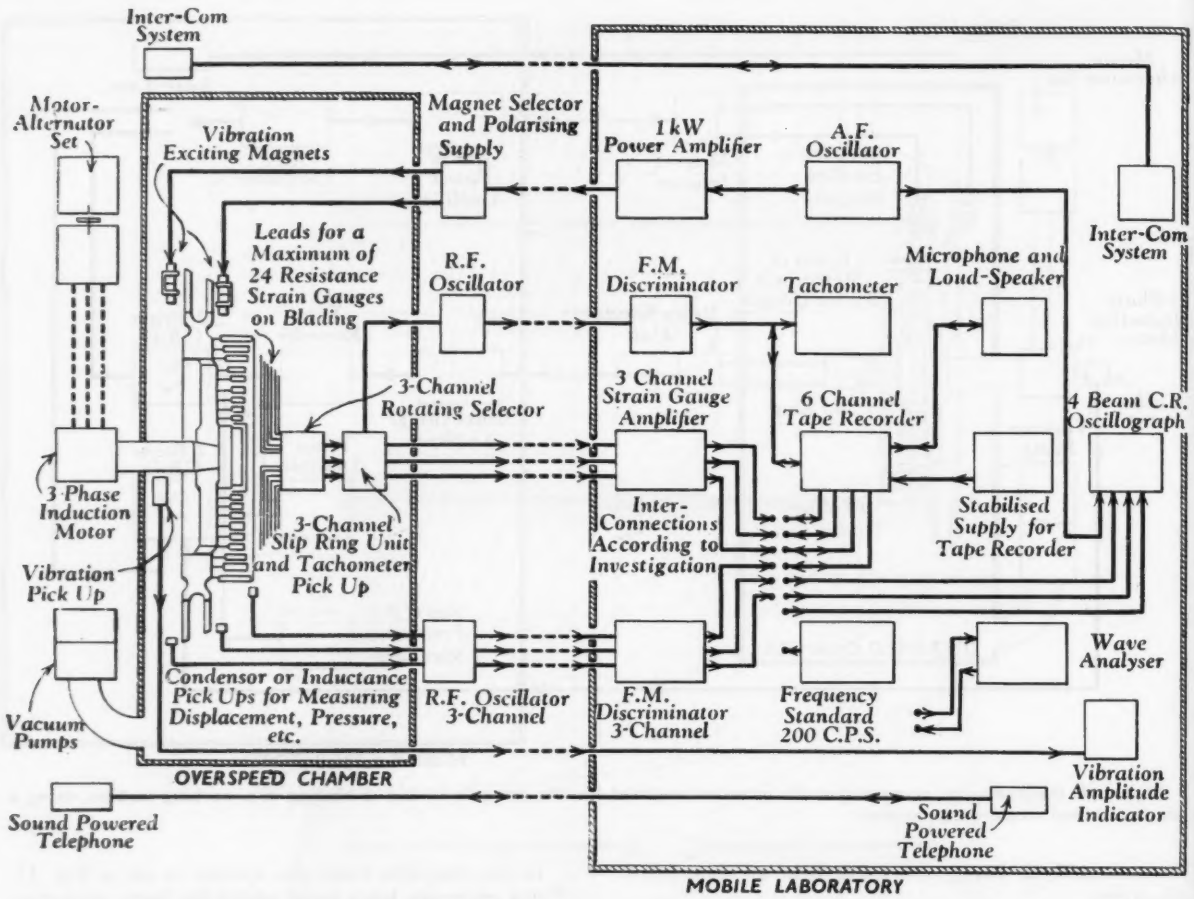


Figure 11. Arrangement of apparatus for obtaining strain measurement and vibration characteristics of turbine blading in an overspeed chamber, using a multi-channel strain-gauge system.

are selected from static test data so as to include the largest frequency variation (scatter) for a particular mode.

The curves in Fig. 9 have been derived as follow: the wave analyzer, set in the narrow band condition, i.e., 3 per cent approximately flat top band-width, is carefully controlled to follow a harmonic line while the tape recording is replaying, the selected spectrum being recorded photographically from an oscilloscope.

In this way a resonance "build up" will be recorded as each intersection of the harmonic line with a characteristic (as yet unknown) is traversed. By obtaining records from a number of harmonic lines in this manner a graph showing characteristics as in Fig. 9 can be completed; the curve indicating the positions of maximum resonance. Finally the wave analyzer, set to a 10 per cent band width, is used to follow each characteristic so obtained, the center of the band width being synchronized with the completed curve of maximum resonance. The photographic records obtained are similar to those shown inset on Fig. 9. During the final operation, the frequency at each maximum resonance is checked by comparison with a precision oscillator.

In Fig. 12, which (as explained above) combines the characteristics from a series of blade packets such as those in Fig. 4, a band is shown for each mode of vibration. As the speed increases it will be noted that the bands become narrower. This is due to the action of centrifugal force tending to equalize differences of root fixity, thus reducing the frequency scatter of the packets.

CONCLUSION

If the design procedure has been satisfactory, the band-width of the packet frequency-speed curve should lie between harmonics at a normal running speed. By comparing observed with calculated behavior the validity of theoretical design methods may be checked. Where these methods have, of necessity, involved assumptions concerning blade fixation or other theoretically indeterminate features, the new equipment described enables these assumptions to be closely examined and makes possible improvements in design practice. By studying past perform-

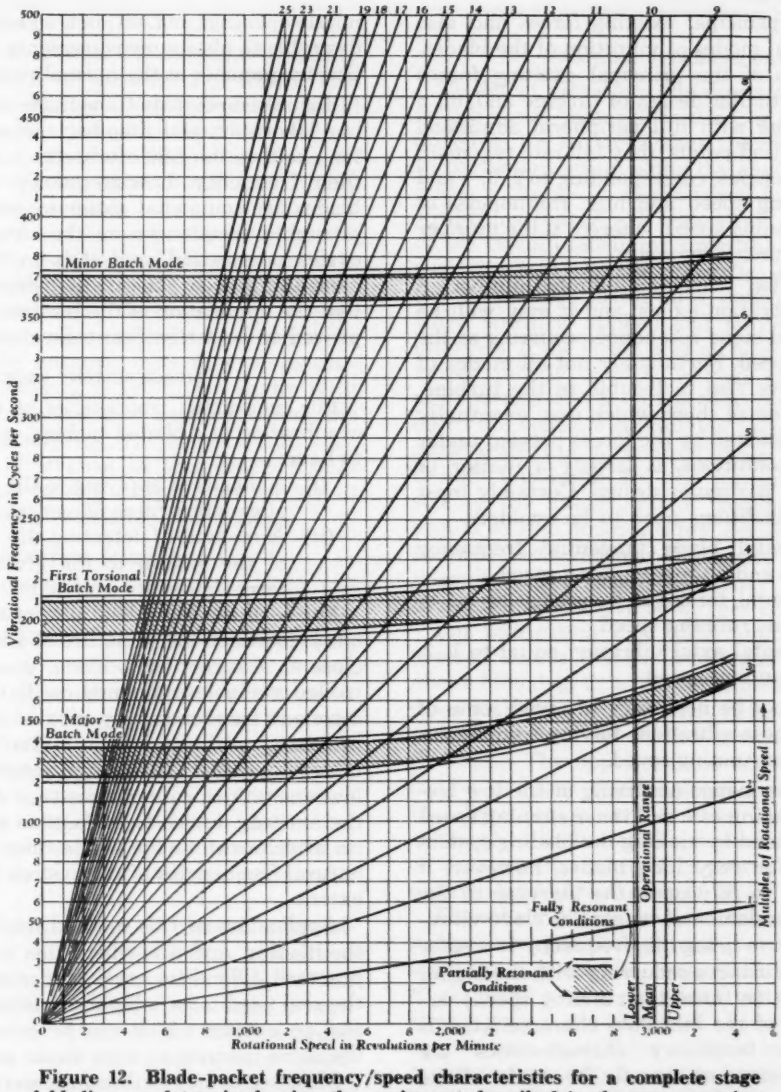


Figure 12. Blade-packet frequency/speed characteristics for a complete stage of blading, as determined using the equipment described in the accompanying article.

ance, the designer is given greater confidence in his ability to make accurate predictions of blade frequencies in cases where new departures from current practice are contemplated. In this sense the initial progress made with the equipment described augurs well for greater control and understanding of turbine blade vibration problems in the future.

II—DEVELOPMENT OF BARIUM TITANATE TRANSDUCERS

IN A STEAM TURBINE, various periodic forces act on the blading. These may arise from unbalanced mechanical forces or from the lack of uniformity of the steam forces applied to each blade. For instance, if, as is normal practice, steam is admitted to the wheel through a number of stationary nozzles mounted as a continuous ring, then each blade will experience a change in force when passing each nozzle. Should a natural frequency range 3,000–6,000 cycles per second for the frequency at which these impulses are received, a resonant vibration of the blading may build up. If this resonance (often in the frequency range 3,000–6,000 cycles per second for stages of large 3,000 r.p.m. machines) occurs at the normal running speed of the machine, then a blade failure by vibration may result.

Ideally, blade vibration could be reduced by eliminating the exciting forces, but this is a condition which is seldom possible in practice. A more practical expedient is to avoid conditions occurring at the running speed; this necessitates a knowledge of the

frequency of the principal exciting forces and also those of the natural modes of vibration of the blades.

The frequencies of the principal exciting forces depend on the particular design of turbine and, on a steam turbine stage with full peripheral admission and no steam bleed-off points, they fall into two main groups: low frequencies, corresponding to 2, 3, 4 and 5 times the running speed and high frequencies of n, $2n$ times the running speed, where n is the number of equally spaced nozzle openings.

On a fully bladed wheel an infinite number of modes of blade vibration exists, and it may well be impossible to avoid some resonance occurring at the normal running speed. Fortunately not all modes of blade vibration give rise to trouble in the turbine, although recognition of those which may eventually produce failure if excited by the forces present under normal running conditions, is largely a matter of experience with a particular design. Certainly most of the following conditions need to be avoided: —

(i) A fundamental blade tangential frequency equal to 1, 2, 3, 4, 5 and n times running speed.

(ii) A fundamental torsional frequency equal to 1, 2, 3, 4 and n times running speed.

(iii) A fundamental axial vibration equal to 1, 2, 3, 4 and n times running speed.

In addition it may be necessary to avoid some of the overtones of these vibrations having frequencies equal to n times the running speed.

The danger of resonance occurring at the low frequencies corresponding to 1 to 5 times running speed can usually be avoided by making the blading system sufficiently stiff. For very long blades, however, it may be necessary to rely upon the increase in the frequency of the fundamental tangential blade vibration due to rotation to bring this frequency to a safer value. To avoid resonances occurring with the higher exciting frequency (n times the running speed) accurate knowledge of the vibration characteristics is required.[1] If the frequency characteristics are known, then a choice can usually be made of the number of nozzle openings so that no dangerous resonance conditions occur at the normal running speed.

Calculations allow an approximate estimate to be made of the frequencies of a few of the modes of wheel and blade vibrations but experience has shown that too much reliance must not be placed on calculations alone. What calculations do suggest is that, provided the blade is firmly fixed to the wheel and the shroud band, the change of frequency with rotational speed is negligible for blade frequencies in the range of the nozzle impulse frequency nr cycles per second, where r is the rotational speed in revolutions per second. Thus, in many applications, measurements of blade frequencies on a stationary wheel will provide data of a sufficient accuracy to enable a suitable choice of nozzle openings to be made. On some wheels, however, the vibration characteristics do not allow much latitude in the choice of the number of nozzle openings and, on such wheels, it is particularly desirable to obtain measurements of the blade vibration frequencies at the normal running speed.

For measurements to be made on a rotating wheel in a laboratory test chamber, means have to be found for exciting the blade vibrations and for measuring their frequency. Low-frequency vibrations of long blades are somewhat easier to deal with than those of higher frequencies in the range 4,000 to 10,000 cycles per second, and it is in the excitation and measurement of these high-frequency vibrations that the application of the barium titanate gauge has proved to be a significant development.

MEASUREMENT PROBLEM

For measuring frequencies of the natural modes of vibration of a bladed turbine wheel it is necessary to have: —

(i) A means of applying to the system an exciting alternating force of any given frequency.

(ii) A method of detecting the vibration response of the system to the given applied exciting force.

For a stationary wheel one of the simplest methods is to attach the armature of a moving-coil exciter close to the root of a blade, energize from a controlled variable-frequency oscillator, and detect the resonant frequencies by means of an electro-static proximity pick-up. In the author's experience it is better to work with a high-sensitivity pick-up and low excitations rather than vice versa. This enables the exciting device to be kept to a small size so that its attachment to the blade does not influence the natural frequencies of the system to any appreciable extent.

Application of this method implies easy access to the blading, and it is where this is not available that practical difficulties arise. Under such circumstances the real need is for a highly sensitive vibration gauge and an exciter which can be stuck on the blade in the same manner as wire strain gauges.

Measurements of vibrations on rotating wheels are, of course, more difficult than on stationary ones. They have been made on a turbine blade by means of a type of wire strain gauge attached to the blade, as for example, by Drew.[2] Here the blade vibrations were excited by the aerodynamic disturbances arising from lack of uniformity of the gas stream, and were of sufficient magnitude to give quite large alternating stresses which could be measured by a strain element of the wire resistance type. Measurements have also been made under laboratory conditions, where the blade vibration has been excited by a stationary magnet or a few air jets or by relying on the unbalancing forces present. The latter method was used by Campbell.[3] In these methods the blade receives an impulsive force each time it passes the magnet, or air jet, and determination of any but the lowest mode of vibration is extremely difficult. For controlled laboratory tests, it is essential that the exciting frequency applied to the moving blade

should be continuous and permit the same flexibility of control as for tests on a stationary wheel. This means that both the exciter and the detector should be small enough to be attached to the blade and rotated with it. Under these conditions the blade vibrations emitted will be quite small and highly sensitive gauges are essential.

Even with tests on a stationary wheel, where the size and weight of the exciter is of little account provided the vibration frequencies are not significantly changed by the attachment, the maximum stresses produced in a blade under normal laboratory tests are not high. In the authors' tests they were estimated to be of the order of $\pm$ 100 lb. per sq. in. With an exciter suitable for use on a rotating wheel, the induced alternating stresses will be less than this, and measurement of stresses of this order is only possible with gauges having many times the sensitivity of a normal wire resistance strain gauge.

PIEZOELECTRIC MATERIALS

The possibility of detecting vibrations by the use of a piezoelectric material in the form of a thin wafer strip attached to the member under test has long held attractions. Such an inherently simple device, highly sensitive to alternating strain, giving as it would a self generated voltage proportional to strain and requiring relatively simple measuring gear, has many advantages over other types of vibration strain gauges. Furthermore, application of an alternating voltage across the material produces alternating strain in the material, so that piezoelectric devices may be used not only to detect vibrations but also to excite them.

The usual single-crystal type of piezoelectric material, such as quartz and Rochelle salt, is a sensitive load-measuring device and it has been used for this purpose in the form of relatively large slabs. Piezoelectric exciters and detectors in the form of probe units have also been used under laboratory conditions for vibration measurements, for example, on gas-turbine blades.[4] Rochelle salt is sufficiently sensitive to be used in the form of thin wafer strips[5] but it can only be used over a limited range of temperature and humidity, and its breaking stress is low. A thin wafer of quartz on the other hand would have an inconveniently high capacitative impedence.

Ferroelectric ceramics, such as barium titanate, are piezoelectric after polarization in an electric field and have very high dielectric constants, a few hundred times that of quartz. Wafer strips of ferroelectric ceramics thus have a much lower impedance than the piezoelectric elements hitherto available. Like other ceramics, thin strips of the material need careful handling but are not unduly brittle for normal use.

The piezoelectric properties of these materials are temperature dependent, and at a certain critical temperature, usually about 100 deg. C., they disappear completely. The properties can only be restored by re-polarization at a lower temperature.

BARIUM TITANATE GAUGES

To detect vibrations the direct piezoelectric effect in the gauge material is used, a charge being produced on the surfaces when the material is strained. In particular, strain along the length of a gauge produces a charge on the silvered faces. For a steady strain this charge will leak away, the time constant of the circuit depending upon the measuring equipment used and on the properties and dimensions of the material, so that a pulse output will be obtained when strain is applied and removed at infrequent intervals. If the strain is of an alternating nature and varies quickly enough, leakage of charge becomes unimportant and a voltage-sensitive device connected to the opposite conducting faces will indicate, to some scale, the alternating strain in the gauge. Although unsuitable for the measurement of steady strains, the lower limit of frequency measurement should extend down to a few cycles per second using suitable electronic gear. The upper limit of frequency is set by the resonant frequency of the gauge and should be well above 50 kc. per second.

For fabrication into wafer units, the material is pressed into a desired shape and then sintered at about 1400 deg. C. to form the ceramic. The sintered discs or blocks are cut into wafer-thin strips of appropriate sizes, and surface ground to the required thickness. The opposite faces are silvered, the coating on one face being extended round one edge on to a bare region on the other face. Thin leads are soldered to both metallic surfaces on the same side of the strip. The material is polarized by applying an electric field of the order of 20 kV per cm. across it.

The sensitivity of a barium titanate vibration strain gauge to longitudinal strains is very high. Measurements on a gauge 1 in. long, ⅛ in. wide and 0.010 in. thick, using a wire resistance gauge to measure the strain, gave a sensitivity of about 3 mV per lb. per sq. in. stress in steel for a vibration resonance at 200 cycles per second, the gauge being connected to the input of a Mullard E800 oscilloscope; this is approximately equivalent to 0.1 volts for 10^{-6} units of strain, a few thousand times the sensitivity of a typical wire resistance strain gauge.

This extremely high sensitivity makes a barium titanate gauge eminently suitable for the detection of small vibration resonances. For this it is not necessary to know the actual strain produced and no attempt has yet been made to calibrate the gauges for precise strain measurement. The gauges can, with care, be removed without damage from a component small enough to be immersed in the glue solvent, or from a readily accessible position, so that pre-calibration of each gauge is possible. Calibration would, however, be somewhat more difficult than for other types of strain gauge, since it cannot be obtained by steady strain measurements.

VIBRATION EXCITERS

Excitation of vibrations is carried out using the converse piezoelectric effect in the gauge material,

strain being produced when an electric field is applied across the material. In particular, strain is produced along the length of the material when an electric field is applied between the two silvered faces, and if the gauge is firmly glued to a metal surface a strain will be induced in that surface. The application of an alternating voltage at a frequency equal to a natural frequency of the member on which the crystal is mounted should cause a resonance to be excited.

Tests were made initially on a stationary wheel using gauges as already described. A gauge was attached by means of a cellulose-base cement to the blade surface a little more than half-way along its length and, after allowing time for drying, was energized by the output from a variable frequency oscillator. Another wafer unit fixed to the blade near to the root was used to indicate the vibration on an oscilloscope screen. It was found that vibration resonances could be excited and measured without difficulty. With 150 volts alternating current applied to the exciter gauge, the current flow from the oscillator was of the order of 10 mA, changing of course with frequency. The output from the indicating gauge was in the region of 10 to 20 mV at the blade resonance.

Comparison with an electro-dynamic exciter, such as is normally used for static measurements, showed that for this particular blade which was just over 7 in. long, the barium titanate exciter gives less response below 3,000 cycles per second for normal working currents and voltages. At higher frequencies the wafer unit becomes comparatively better and above 5,000 cycles per second is to be preferred.

In order to avoid cross interference between the gauge units it is essential to use screened connections to the units, with the shielding earthed, and to interpose some shielding between the gauge units themselves. It was convenient, in the laboratory arrangements, to have the gauges on opposite sides of the blade and to ensure that the wheel was connected to earth.

There seemed to be no reason why this arrangement should not be suitable for rotational tests and it gave hopes of a simple measuring technique.

TESTS ON ROTATING WHEELS

The wheel tester built at Fraser and Chalmers works for the measurement of vibrations on rotating wheels has already been described.[6] This tester was designed with the primary object of measuring disc vibration frequencies on rotating wheels, using an electromagnetic exciter held stationary in space close to the rotating wheel to excite these vibrations.

The wheel for test is mounted on a short shaft; this shaft runs in two bearings inside a casing which can be sealed by means of a removable top half and evacuated to a high vacuum. The wheel is driven by an electric motor through a shaft which passes through the casing and is connected to the removable shaft by a Bibby coupling. Slip rings of 7 in. diameter, designed for use with magnetic pick-ups, are built on to the driving shaft. Wheels can be rotated in this tester to well above 3,000 r.p.m.

To prepare the wheel for rotation, the screened leads to the gauges were taken radially across the disc surface and glued firmly in position. The lead from the exciter was taken through the shaft coupling to the slip rings integral with the driving shaft and thence to the output from a variable frequency oscillator. The indicator leads were taken through the center of the shaft to a slip ring unit attached to the free end of the shaft. These slip rings were of conventional design for use with wire resistance strain gauges, with silver-plated rings ⅞ in. diameter and silver morganite brushes. The signal was passed through a filter unit to an oscilloscope and the frequencies measured using a calibrated oscillator.

Vibrations of the blade were excited and measured at frequencies between 1,200 cycles per second (the fundamental tangential mode) and 11,000 cycles per second at rotational speeds up to 3,000 r.p.m. The stresses induced in the blading by the exciting gauges are small, even at resonance and are, in fact, generally less than the stresses produced by low-frequency vibrations excited in the wheel by unbalance effects. These latter vibrations are, for this test arrangement, generally less than 300 cycles per second and can conveniently be screened by a high-pass filter.

The output from the indicating gauge at a blade vibration resonance is of the same order as for a static test, i.e., $\pm$ 10 to 20 mV, and varies from mode to mode and also with speed due to changes in blade damping. With a signal of this magnitude only minor slip ring troubles were encountered.

No difficulties arose from adhesion of the leads or gauges. The gluing technique used is the same as in normal practice for wire resistance strain gauges and a gauge unit complete with screened connecting cable has been successfully rotated at a radius of 24 in. up to a speed of 3,900 r.p.m.

Tests have now been made on many turbine wheels fitted with blades of different length and design. It has been possible to explore the frequency changes which occur as speed is raised, from the lowest vibration mode of long blades at frequencies between 300 to 350 cycles per second, up to high overtone modes with frequencies of many thousands of cycles per second. The measurement of the lowest frequencies requires the greatest care, and certain precautions are necessary to reduce the signal from the self-excited disc vibrations which occur.

If the wheel for test is mounted on a solid cast-iron bush it will become loose at some speed which, for a reasonable interference fit, will be well below 3,000 r.p.m. When this occurs a marked increase in extraneous wheel vibration is usually noted. By mounting the wheel on a flexible bush designed to hold it up to 3,000 r.p.m., or slightly above, the ex-

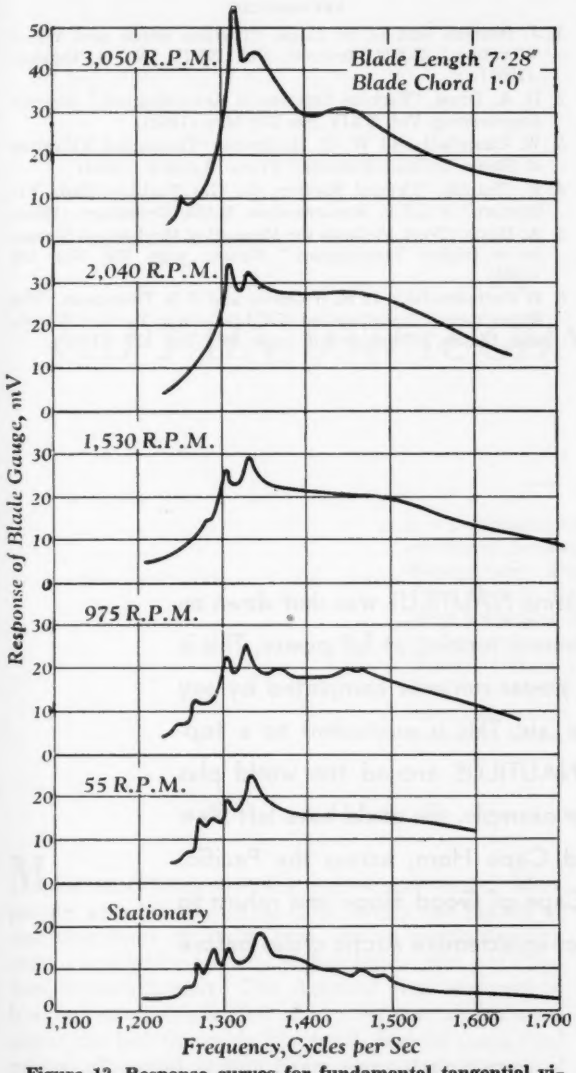


Figure 13. Response curves for fundamental tangential vibrations of a steam turbine blade at various speeds of rotation. The response is measured by the gauge output in millivolts.

traneous vibrations at the higher speeds may be substantially reduced.

By suitably tuning the gauges it is often possible to reduce unwanted signals. For instance, when it is particularly desirable to eliminate, as far as possible, the pick-up from nodal diameter wheel vibrations, much can be done by using two barium titanate gauges attached, at the same position, to adjacent blades. The gauges are connected in opposition so that a similar vibratory strain in the two blades will give a minimum response. For a nodal-diameter wheel vibration the movement of two adjacent blades will be nearly, but not quite, the same and as the sensitivity of the gauges may also be slightly different, it is usually necessary to adjust the sensitivity of one of the gauges until the response is a minimum. This is done by carefully removing minute portions of the silver coating of the more sentitive gauge until the response of the gauges to a nodal-diameter wheel vibration is substantially reduced. If this tuning is done on a stationary wheel while it is being excited at a particular nodal-diameter vibration it is possible to reduce the signal to about 5 per cent of that from a single gauge.

For the long blades on which this method has been used, the decrease in response to a blade vibration excited by a barium titanate exciter attached to one blade was small, and with the signal from nodal-diameter wheel vibrations reduced the blade vibrations were more easily detected and measured.

As an example of the type of measurements which have been made, Fig. 13 shows curves of blade response as measured by a barium titanate wafer unit for the fundamental tangential blade vibrations of a 1 in. chord blade 7.28 in. long, at various rotational speeds up to 3,000 r.p.m. The response is measured in millivolts and as the circuit arrangement was identical for each test the results give a direct indication of the change in damping which occurs in the blade assembly as the speed is changed. The response curves shown are typical of this type of blading system and show that many resonant peaks occur within a small frequency range. It may also be noted that the resonance giving the maximum response at 3,000 r.p.m. is not necessarily the same resonance that gives maximum response on the stationary wheel. This occurs, no doubt, because damping changes due to rotation affect different modes in slightly different ways, but it is clear that if isolated measurements of the frequency for maximum response are made at 3,000 r.p.m. and on a stationary wheel, the apparent effect of centrifugal forces on the blade vibration frequency would be misleading. By a full exploration of the resonance regions such as is indicated by the response curves a much clearer picture of the changes which occur as the speed varies is possible.

CONCLUSIONS

In general the barium titanate gauges can be considered as supplementing rather than superseding other simple types of vibration detectors. For precise vibration stress measurement, precalibration of each gauge before use appears to be necessary, and as this type of gauge cannot be calibrated by applying steady strains, their application for quantitative stress measurements is likely to be restricted to research investigations where the advantages of size and sensitivity are overriding. The gauges do, however, fill the very real need which exists at present for a simple highly sensitive alternating strain detector for resonance indication, particularly for strain levels too small for wire resistance strain gauges.

The use of the gauges as vibration exciter units allows considerable freedom in the positioning of the exciting device even on small components, since the exciting unit may be very small and weigh little

more than a conventional wire resistance strain gauge. Because the exciting device is in intimate contact with the member it is desired to vibrate, the input power required to excite the vibrations is kept to a minimum and no elaborate electronic circuitry is required. The gauges permit an easy means of exciting vibrations in lightly damped parts of rotating bodies. The ferroelectric ceramics used to make the gauges lose their piezoelectric properties around 100 deg. C. and an upward extension of this limiting temperature would increase the field of usefulness. There is a possibility that the development of improved materials may give an increase in the maximum working temperature.

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The land-based prototype of the submarine NAUTILUS was shut down on 8 August, 1956, after 66 days of continuous running at full power. This is believed to have been the longest full power run ever completed by any type of propulsion plant—land, sea or air. This is equivalent to a top-speed, submerged, steaming of the NAUTILUS around the world plus many thousands of miles in addition. For example, she could have left New London, Connecticut, steamed around Cape Horn, across the Pacific, across the Indian Ocean, around the Cape of Good Hope and return to the starting point; and then continued for an extensive Arctic cruise before scheduled shut down.

A naval diving record was set recently in Norway's Sor Fjord by a British diver from H. M. salvage ship RECLAIM. A depth of 1060 feet was attained in a conventional observation chamber.

CAPTAIN JOHN ADRIAN HACK, U. S. Navy

CAPTAIN O'SHAUGHNESSY LEARNS A LESSON

THE AUTHOR

is a graduate of the U. S. Naval Academy in the Class of 1935. After varied service in destroyers and submarines he received post graduate instruction in Management Engineering at Rensselaer Polytechnic Institute in 1949–50. Since then he has been able to observe many of the applications of management principles in the Fleet. He has served as Executive Officer of a destroyer tender, commanding officer of the USS EPPING FOREST, and as both Maintenance Officer and Assistant Chief of Staff for Operations and Plans on the Staff of COMCRUDESPAC. He is at present a student at the Naval War College. This article, the fifth about Captain O'Shaughnessy, describes some of the measures taken in recent years to improve the material conditions in ships.

MICHAEL O'SHAUGHNESSY turned and tossed! Most people, at a time like this could enjoy the luxury of counting lines of white little lambs, neatly leaping over a low white painted picket fence. But not Captain O'Shaughnessy. The Admiral had lectured to him so convincingly that afternoon that sheep were about the last things on his mind. Instead main feed pumps glowered at him from every dark corner of his room. The trees outside cast shadows of boiler tubes across the ceiling, wavering until they became so real they were about to fall onto him. An innocent cricket outside, happily singing its last song of the evening, sounded like a bearing just about to wipe! Turbines whined in the breezes which whipped around the corner of his house. Even when he shut his eyes he could see the endless parade of broken down machinery, marching piece by piece across the gangways of the trim destroyers up into the shops of the shipyards, while the officers and men in the ships busily made out work requests to insure that the parade did not stop. At long last the fatigue of endless days of worry blest him with sleep!

O'Shaughnessy was no exception in the Fleet! Ships were getting older. Personnel weren't as plentiful as they had been when he had first come into the service. And the equipment was so much more complex. In the good old days, a Captain coming into port need only mend a few broken oars, pick out a few husky looking slaves and put to sea, confident that his motive power would get him into the battle. Later, scientific advances required him to acquire the services of a fellow fast with the needle and thread, as sail supplanted the oar. Given a good breeze and a strong sail, the Captain of any warship could call for full power merely by wetting a finger and holding it up to the wind.

O'Shaughnessy's large generous mouth broke into a wide grin. As Assistant Chief of Staff for Logistics he had just called a conference and passed along to each of the commanding officers of the force the experience of his years . . . "mind your canvas and your lines, take along a goodly supply of lemon juice, and you'll have no maintenance problems. Clean out the gun barrels once a day, and keep your powder dry. That gentlemen just about winds it up." But the dawn awakened O'Shaughnessy and brought him back to reality and the twentieth century. Brought him back to the stark fact that as Assistant Chief of Staff for Logistics, he had to do something constructive to improve the material conditions within the force, somehow awaken the spirit of self sufficiency that has permeated every fighting ship from the days of Noah to Admiral King, and if it were at all possible insure that every essential repair

to any ship of the force was insured in spite of a constantly contracting budget.

The words of the Admiral still rung in his ears! "O'Shaughnessy, the only purpose of a navy ship is to carry its destructive power to a potential enemy. Sure our ships are getting older, but so are a lot of the hot rods I see our boys racing up and down the highways in. And I wish you could have seen the one which passed my '56 Olds on the road last night. As for the personnel inexperience, I'll grant that we don't have the depth in strength that we had when you and I were young, but these kids still have the brains . . . they just seem to lack direction. We're floundering, O'Shaughnessy, and I'm worried. The repair bills are mounting and mounting. The thing that really has me concerned is that we've passed the stage in America when we can waste! Every dollar spent by our ships, when it didn't have to be, ultimately comes out of the new construction which we so desperately need. Equipments are complex.

"But I'm not too sure that we haven't listened too keenly to the propaganda of despair, and forgotten what our basic problem really is! I've heard all about our problems and the reasons for them. But Mike, has the thought occurred to you, as you worry about the THINGS that are giving us trouble . . . boilers, main feed pumps, ship's service generators, turbines . . . that these are just poor dumb pieces of metal. Men are responsible for our achievements, O'Shaughnessy! Perhaps men are also responsible for the troubles we're having. Perhaps, the answer to our problem lies in a better management of the men we have!"

"Were the officers as good as they used to be?" O'Shaughnessy asked himself in the cold gray of dawn. They weren't doing things the way he thought they should, the way he had done them as he came up the hard ladder. The Captains knew their ships, or at least thought they did! But boilers didn't get cleaned. One thing after another in the ships happened. A ship's service generator would have a zero ground, and burn out an armature, because it hadn't been cleaned. Gun batteries were not in alignment. And the troubles carried over into the other fields as well. Men came to mast in a parade of minor offences. Trivial absences over leave, the most of them, but just a minor sign of irresponsibility just the same. Re-enlistment rates were going up, but still they weren't anything to brag about compared to earlier days O'Shaughnessy remembered. Men passed their advancement in rating exams then couldn't demonstrate their practical qualifications. In fact, it distressed him that many of his troubles, as he pored over work requests and casualty reports, were matters that the Advancement in Rating Qualifications so rigidly pronounced that these men had demonstrated a proficiency to accomplish. Perhaps there were just too many things for a commanding officer to remember!

Mike switched on the lamp by his bed and his hands picked up the weatherbeaten Bible. With his world heavy on his shoulders he sought solace in the Bible, as he had through the years. By chance he turned to the book of Deuteronomy. His eyes picked up the lines which start with the first chapter, ninth verse. They didn't mean too much at first. Then suddenly they did! Perhaps you remember how Moses addressed the Jews on that day, long ago in the heat of the desert, somewhere between Egypt and Palestine.

"At that time (in the desert) I said to you, 'Alone I am unable to carry you. The Lord, your God, has so multiplied you that you are now as numerous as the stars in the sky. May the Lord, the God of your Fathers, increase you a thousand times over, and bless you as He promised! But how can I alone bear the crushing burden that you are, along with your bickering?' 'Choose wise intelligent and experienced men from each of your tribes, that I may appoint them as your leaders!' You answered me, 'We agree to do as you have proposed.' So I took outstanding men of your tribes, wise and experienced, and made them your leaders as officials over thousands, over hundreds, fifties and over tens, and other tribal officers. I charged your judges at that time, 'Listen to complaints among your kinsmen, and administer true justice to both parties even if one of them is an alien. In rendering judgement do not consider who a person is; give ear to the lowly and to the great alike, fearing no man. For judgement is God's. Refer to me any case that is too hard for you and I will hear it!"

The next day O'Shaughnessy had the start of many conferences with the commanding officers of the force, and as many others as would listen. "Moses had quite a problem," he'd explain, "When his followers were few he had been able to guide them effectively and in a most personal manner. Then when they got so numerous he couldn't stand the burden of doing everything himself. In fact things got so bad that the men started to bicker among themselves, and wonder how they could get out of his outfit. So he decentralized. He appointed leaders over thousands, and their leaders were over hundreds, then fifties, then tens. Moses gave his leaders their commands, and warned them to listen to the complaints of their men no matter how lowly their position. Finally, they were to come back to him for any solution which was too much for them. Moses delegated his responsibilities and his authority, so that everyone had a job to do and the authority to do it. He made policy then expected it to be carried out. He managed by exception . . . only those matters beyond the capabilities of his subordinates were referred to him.

"I'm sure none of us are as smart as Moses. Yet, anxious to please, and eager to get a job done, we are trying to be! Sometimes as Commanding Officers we are all over the ship, telling every man how to do his job, personally attempting to supervise every little detail, never listening to advice. Indeed never asking for it! Our burdens are more overwhelming than when we were younger simply because there

are more people and therefore more problems to which we must give our attention. Ships are complex! Why even Moses couldn't command one and handle every detail all by himself. Nor could he, were he the commander of a shipyard, expect that he and his leaders could ferret out every bit of trouble and put a ship back in running order again! No wonder our ships are having their troubles. No wonder morale of our men isn't what it should be. No wonder they aren't able to train for advancement in rating, operate their guns, machinery and electronics gear to the best of their utility. We've been trying, in our mistaken sense of duty, to do everything ourselves. We've tried to outdo even the great Moses! He had to organize his followers! We have to organize ours! If our men are to follow us we have to lead them . . . not get behind them and shove. Even the lowly fireman *might* have some good ideas. But if we are to benefit from those ideas, we must insure that our ship becomes *his* ship.

"How many times have we lost patience with a lad when we saw him doing something different than we would have done it. How many times have we invited a shipyard commander to inspect our ships and tell us what ought to be done during an overhaul, without even asking our individual men? How many details have we caused to be brought to us for decision? No wonder our burdens are crushing us, and we get the illusion that our men are irresponsible and incapable. We can't remember everything, but each one of them can, if we allow them to, remember something which he is made responsible to do every day as a specialty.

"Gentlemen, we all wish that each of us had the best ship in the Fleet. You know and I know that you don't. Machinery doesn't get maintained. We rely on shore activities to tell us what repairs we need. Our training programs haven't produced the results we have wished. The enlisted man has the feeling that he isn't really an important man on board, yet we all know he is. I must admit that much of our problem lies on my shoulders. When I first came to this staff I made the mistake of imagining that this maintenance problem was *mine* to remedy, and that I could lick it of my own accord. Age and experience sometimes teach us so much that we forget the fundamentals in life. For I do know how to overcome every problem we have, and have made the mistake of telling you in detail how to handle every situation in maintenance and repair as it came up. I have encouraged shipyards to make repairs in your ships at their initiative, you having only to sign the papers 'requesting' that machinery be made to run correctly by doing the things their inspectors said had to be done. I became so eager that our ships would be reliable, that I neglected the very men who are able to make them so.

"This problem is my problem, true. But more immediately it is the problem of every man in our ships. You should set the standards, and they need only be simple ones. Every item of machinery, every piece of equipage, every compartment on the ship, must as a matter of routine be cared for. The preventive maintenance, the shipboard repairs, and the initiation of the action to repair things which our ships cannot, should be the routine responsibility of an individual. The training of the men should be such that every man who has spent the appropriate time in rate, should be able to pass his examinations, including the demonstration of the skills required by that rate. And above all, gentlemen, let's not forget, every achievement that one of our ships gains, must of necessity be the result of an individual's efforts. Let's make sure that he knows that we appreciate it, with some tangible reward . . . an extra liberty, a commendatory mast, perhaps even a letter of commendation from the Admiral."

That was a year ago. Yesterday Captain O'Shaughnessy accompanied the Admiral to one of the destroyers to award a letter of commendation to one of the commanding officers. His ship had won the unofficial Battle Efficiency competition, an Engineering and an Operations "E." Everyone on the Staff had been, at one time or another, talking about this particular ship. She had undergone a shipyard overhaul with less expense than any destroyer during the year. She hadn't been in a restricted availability except for a boiler repair, and that only after the ship had pointed out the results of their careful inspection. Her re-enlistment rate was high. The Admiral is a nice guy. He wanted to find out for himself what was so different about this ship, from those which had prompted his tirade at O'Shaughnessy a year ago.

In the wardroom, over a cup of coffee, Commander Smith talked with the fervor of a man in love. He didn't tell the Admiral anything which he didn't already know . . . just reviewed some fundamentals of Navy life which we sometimes forget in the complexities around us.

"Admiral," he began, "after that talk that Captain O'Shaughnessy gave us a year ago, I came back to the ship and got all the officers together while the ideas were still fresh in my mind. I had no false illusions of reaching Utopia. Until we get to Heaven we're not going to be perfect. But we could try! Well, we talked for several hours, and in that initial meeting began a phenomenon which was to see the entire ship transformed into a group of amateur management engineers. We didn't have all the textbooks which spoke of span of control, areas of responsibility, division of labor, and other principles of which we had all heard but never quite understood. No, we arrived at our solutions by using the basic intelligence with which God had blessed us.

"Since our maintenance problems were uppermost in our minds, our attentions were drawn to that area first. We agreed that if a specific individual on the ship was going to be assigned the responsibility for *each* item of machinery and equipage, the first thing we had to do was to find out what we had aboard. The Executive Officer checked the hull sheets with each division officer to insure their accuracy. Then

armed with these, the officers spent an entire day compiling a complete inventory of every item of machinery and equipage, compartment by compartment.

"The next day we had another meeting. Armed with Navy Regulations and the inventory of machinery items, the Executive Officer began the tedious process of assigning each compartment, each item of machinery to an individual department head." Smith chuckled as he continued, "Admiral, it wasn't quite as clearcut as I had imagined it would be. So many of the officers had protested that all this work was un-necessary, yet when the items were called out we all learned a very important lesson. In some instances two different department heads would lay claim to the same item. Others no one accepted, and strange as it sounds, we were all surprised that some of these things even existed. Before that morning was over each item in our ship was the direct responsibility of one department head. Following NWIP-50 and Navy Regulations, it was not difficult to take the next logical step in our quest for perfection. The lists we had compiled were subdivided into appropriate sections for each department. For example, within the Engineering Department we assigned appropriate items to Main Propulsion, Electrical and Damage Control. The Gunnery Department had one list for Gunnery and one for Deck. Even the Supply Department, much to the amazement of the Supply Officer, who had never considered that preventive maintenance came under his responsibility, had such an itemized list. We had thus assigned to each junior officer on the ship, specific compartments, items of machinery and of equipage, which were hereafter to be his sole responsibility to have maintained and repaired. Just as we had to rely upon the junior officers to achieve this step, it became obvious to all of us that to proceed further we would have to call upon the Chief and First Class Petty Officers to continue.

"Admiral, the reaction of the men surprised me to say the least. For some this was the first time that they had ever been consulted in any planning function by their admittedly inexperienced officers. These responded with enthusiasm. Others saw this program as a change. They had never been faced with such clearcut responsibility. They could see that inevitably there would be trouble with machinery and spare parts. None of us like to stand out like sore thumbs as being the cause of a snafoo, and these men were no exception. But with the enthusiasm of some, and the misgivings of others, we succeeded in compiling a list of things to be cared for, down through the department echelons. Some were associated by physical location; other subdivisions were made as a result of the peculiarities of the equipment, and the special skills required to operate and maintain these. But by and large, either according to physical location or technical peculiarity, the inventory was completed. Finally, the petty officers who had more detailed technical knowledge than the officers, grouped these items into jobs which the *average* man could accomplish, each item of machinery (or group of items) being described as a specific job 'accomplish preventive maintenance (using a check off list as a reminder); accomplish shipboard repairs required; initiate the action to replace spare parts used; and initiate the action required to insure repair if beyond your capability (by making out a work request).'

"For the first time, on my ship, we had an Organization for Maintenance. Each gun, each pump, each motor had a very personal interest for its welfare by one individual. At every echelon, a specific responsibility was appreciated for the first time. And for the first time, when the announcing system implored 'turn to!', each man jack knew where he was to go in as orderly a fashion as when the word was passed 'All hands to General Quarters.'

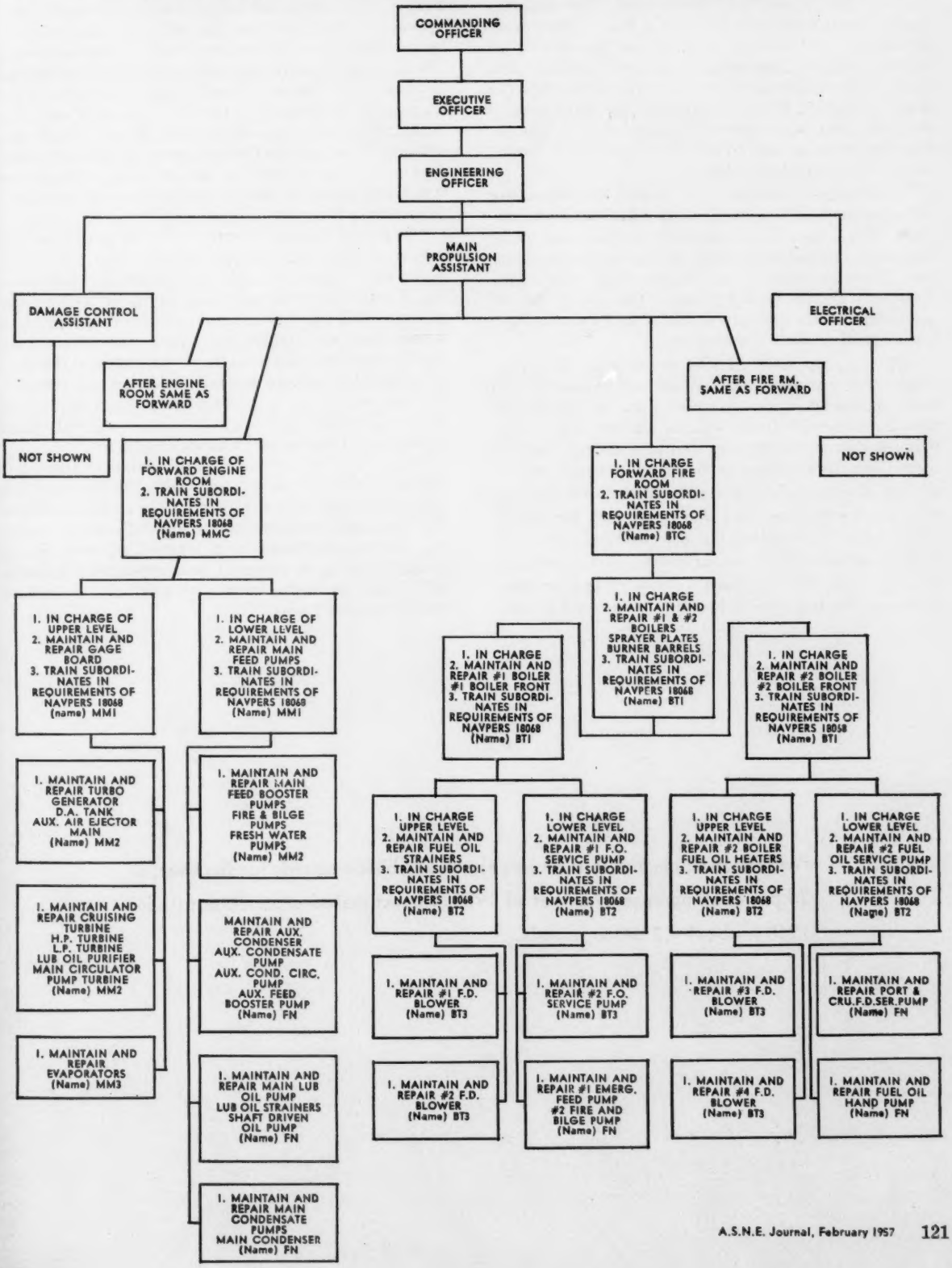
"That was our modest start. But we still hadn't licked our other problems. One of the Chiefs had been examining the Requirements in Advancement in Rating, NavPers 18068. 'Do you know,' he exclaimed to one of the officers with the same pride which Columbus must have felt as he discovered America, 'that the things which a man has to demonstrate he can do before he gets advanced in rating, are the same things he or his boss are supposed to do in this new organization? He has to maintain certain items of machinery and demonstrate that he can operate them properly. All we need to do is to write in jobs for the supervisors to train those who work under them, in terms of these requirements.'

"And so before the week was out, our ship had a clearcut Organization for Training and Maintenance.

"The first time we went alongside a tender," Commander Smith spoke with the pride of a man in love with his first girl, "I have never seen such furor. Before that each man thought someone else would worry about work requests. That time every man who had a piece of machinery which wasn't working properly, was demanding to know why someone from the tender wasn't working on it. They worked as though they had just found a room full of new toys; watched to see how the experts made the repair. Individuals discovered that spare parts weren't aboard to fix HIS piece of machinery, and started to apply the pressure up the chain of command to get them." Smith chuckled, "One fireman *demanded* that his boss produce a gasket, and shoved a 307 form right in his face as an incentive. He'd even gone to the supply office to find out how to fill it out! It wasn't that the men were afraid. They just didn't want THEIR little part of the ship to be in anything but first class shape.

"The men were putting the pressure on their bosses, and the pressure finally reached up to me. Training was being conducted, machinery was getting repaired, repair parts were being procured, and finally the initial wave hit my desk. The Supply Officer was first. He demanded that I go over to the Staff and request an augmentation to the ship's allotment.

ORGANIZATION
MAINTENANCE TRAINING AND ADMINISTRATION


COMMANDING OFFICER
EXECUTIVE OFFICER
ENGINEERING OFFICER
MAIN PROPULSION ASSISTANT
DAMAGE CONTROL ASSISTANT
AFTER ENGINE ROOM SAME AS FORWARD
ELECTRICAL OFFICER
AFTER FIRE RM. SAME AS FORWARD
NOT SHOWN
NOT SHOWN
1. IN CHARGE OF FORWARD ENGINE ROOM
2. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) MMC
1. IN CHARGE FORWARD FIRE ROOM
2. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BTC
1. IN CHARGE OF UPPER LEVEL
2. MAINTAIN AND REPAIR GAGE BOARD
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (name) MMI
1. IN CHARGE OF LOWER LEVEL
2. MAINTAIN AND REPAIR MAIN FEED PUMPS
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) MMI
1. IN CHARGE
2. MAINTAIN AND REPAIR #1 & #2 BOILERS SPRAYER PLATES BURNER BARRELS
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BTI
1. IN CHARGE
2. MAINTAIN AND REPAIR #1 BOILER #1 BOILER FRONT
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BTI
1. IN CHARGE
2. MAINTAIN AND REPAIR #2 BOILER #2 BOILER FRONT
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BTI
1. MAINTAIN AND REPAIR TURBO GENERATOR D.A. TANK AUX. AIR EJECTOR MAIN (Name) MM2
1. MAINTAIN AND REPAIR MAIN FEED BOOSTER PUMPS FIRE & BILGE PUMPS FRESH WATER PUMPS (Name) MM2
1. IN CHARGE UPPER LEVEL
2. MAINTAIN AND REPAIR FUEL OIL STRAINERS
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BT2
1. IN CHARGE LOWER LEVEL
2. MAINTAIN AND REPAIR #1 F.O. SERVICE PUMP
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BT2
1. IN CHARGE UPPER LEVEL
2. MAINTAIN AND REPAIR #2 BOILER FUEL OIL HEATERS
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Name) BT2
1. IN CHARGE LOWER LEVEL
2. MAINTAIN AND REPAIR #2 FUEL OIL SERVICE PUMP
3. TRAIN SUBORDINATES IN REQUIREMENTS OF NAVPERS 18068 (Nagne) BT2
1. MAINTAIN AND REPAIR CRUISING TURBINE H.P. TURBINE L.P. TURBINE LUB OIL PURIFIER MAIN CIRCULATOR PUMP TURBINE (Name) MM2
MAINTAIN AND REPAIR AUX. CONDENSER AUX. CONDENSATE PUMP AUX. COND. CIRC. PUMP AUX. FEED BOOSTER PUMP (Name) FN
1. MAINTAIN AND REPAIR #1 F.D. BLOWER (Name) BT3
1. MAINTAIN AND REPAIR #2 F.O. SERVICE PUMP (Name) BT3
1. MAINTAIN AND REPAIR #3 F.D. BLOWER (Name) BT3
1. MAINTAIN AND REPAIR PORT & CRU.F.D.SER.PUMP (Name) FN
1. MAINTAIN AND REPAIR #2 F.D. BLOWER (Name) BT3
1. MAINTAIN AND REPAIR #1 EMERG. FEED PUMP #2 FIRE AND BILGE PUMP (Name) FN
1. MAINTAIN AND REPAIR #4 F.D. BLOWER (Name) BT3
1. MAINTAIN AND REPAIR FUEL OIL HAND PUMP (Name) FN
1. MAINTAIN AND REPAIR EVAPORATORS (Name) MM3
1. MAINTAIN AND REPAIR MAIN LUB OIL PUMP LUB OIL STRAINERS SHAFT DRIVEN OIL PUMP (Name) FN
1. MAINTAIN AND REPAIR MAIN CONDENSATE PUMPS MAIN CONDENSER (Name) FN

Presenting me with an itemized list of our requirements, he informed me forlornly that he couldn't face the other department heads unless he could produce the parts they demanded. The training course requisitions hit me like a wave! Men were demanding instruction! No one had mentioned an organization for administration, but we had one. Each of these pressures was flowing upward in an orderly fashion. Those which could be taken care of along the way were weeded out and solved. The remainder were getting to my level and action wasn't expected, it was demanded!

"Somewhere I had read, or heard that authority and responsibility went together like love and marriage. They were as inseparable as boys and girls! My ship was operating with delegated responsibilities. It was up to me to put the frosting on the cake. Authority should be delegated to those with the responsibility. The Executive Officer and I worked out my method of such a marriage.

"On our ship each man knows that he is responsible for the proper maintenance and repair of each item of machinery assigned to him; he knows his training responsibilities both as teacher and as student; and finally he knows that his conduct must be a credit to the ship and to the Navy. It is the responsibility of every officer and of every man on this ship to *reward* everyone who works directly for him if these basic responsibilities are fulfilled. Rewards may be in the form of special liberty, commendations by me, or at the very least a word of appreciation. Admiral, when a man is brought to me by his petty officer for commendation, the effect is miraculous. I get a glow from an accomplishment of one of my men. The petty officer feels that he is an important fellow, who can on his say so determine whom I will commend. And the man. He wouldn't dream of letting either of us down after such a commendation. The feeling of pride and enthusiasm is as contagious as small pox! There is a subsidiary policy. Only the Captain is authorized to punish anyone. It isn't that I don't trust my petty officers and officers; I just want those men who do not measure up to their responsibilities to hear it from me face to face. At least they can never complain that they don't have access to me even under those circumstances.

"Admiral, I hope I haven't bored you with this outburst, but I wanted you to know that I don't deserve the Commendation you handed me this morning. I really don't do anything. My men and my officers do it all for me, and just require that I produce when they are unable to. Every one of my men knows that he is the most important man on the ship. He regulates his own rewards, his personal prestige, and his well being in general by his own efforts. Do you realize that the Navy is just about the only place in the world where that can still happen?"

Going back to the flagship the Admiral turned to Captain O'Shaughnessy, and said, "That young fellow didn't tell us one thing we didn't already know. Yet he taught us more about self sufficiency, economy, and morale than we've learned all year. Sometimes in being so paternal, and attempting to solve all of our problems by our own efforts, we get all mixed up, don't we?"

Production of plastics in 1956 was about 3½ billion pounds for the year, a 26 per cent increase over that of 1955. The estimated production rate in 1960 is about 7.2 billion pounds.

"THE WELDING JOURNAL"

FABRICATION OF THE HOMOGENEOUS REACTOR TEST VESSEL ASSEMBLY

ACKNOWLEDGEMENT

This article is reprinted from the October 1956 edition of "The Welding Journal." It was presented at the National Spring Meeting of the American Welding Society in Buffalo, N.Y., May 7-11, 1956, by L. F. Bledsoe and F. V. Daly, of the Newport News Shipbuilding & Drydock Co.; G. E. Elder, of White Sands Proving Ground; and W. R. Gall and E. C. Miller, of Union Carbide Nuclear Co.

INTRODUCTION

The Homogeneous Reactor Test (HRT) is the second experimental aqueous homogeneous reactor which will be operated by the Oak Ridge National Laboratory of the Union Carbide Nuclear Co., as a part of the Atomic Energy Commission's program to evaluate the feasibility of this type of reactor for the production of industrial power. The reactor vessel, including the core tank, was fabricated under contract by the Newport News Shipbuilding and Dry Dock Company.

An earlier, smaller reactor, the Homogeneous Reactor Experiment (HRE),[1,2] demonstrated the ability to produce substantial amounts of power, the inherent nuclear stability of the homogeneous type reactor resulting from the negative temperature coefficient of reactivity, and the relative simplicity of operation, control and fuel handling.

Purposes of the present reactor, the HRT, include:[3]

1. Determination on a larger scale than the HRE, of the engineering reliability, in a reactor system, of both the conventional and relatively unconventional materials and components, including the reactor vessel and the zirconium alloy core tank;
2. Testing and demonstration of products for continuous chemical processing to remove reactor products;
3. Demonstration of the feasibility of the system as an operating power reactor.

It was necessary to design and build a reactor of substantial power output to accomplish these objectives within the confines of a definite construction schedule, and yet retain the flexibility, replaceability and moderate cost of an experimental system. For these and other reasons, it was determined that the reactor should have an operating heat output of 5 megawatts with a possible maximum of 10 megawatts, a specific power of 17 kw per liter, a core diameter of 32 in., a blanket (fluid) thickness of 14 in., a fuel outlet temperature of 300° C, and an operating pressure of 2000 psi.

The reactor vessel assembly is shown in Fig. 1. The 32-in. diam core vessel was fabricated from 5/16-and 3/8-in. thick plates of Zircaloy-2, a zirconium-tin alloy containing small amounts of Fe, Ni and Cr. The core tank fits approximately concentrically within the 60-in. ID pressure vessel, which is the main container for the 2000 psi operating pressure. This vessel is made of 4-in. thick carbon steel hemispheres (SA 212, grade B, manufactured to SA 300 practice), internally clad with a 0.4-in. thick layer of Type 347 stainless steel. The entire pressure vessel assembly is further contained within a 1½-in. thick Type 304 stainless steel spherical blast shield, spaced 1 in. from the pressure vessel outer wall. The blast shield is a safety device intended to stop fragments in the improbable event of a sudden brittle failure of the pressure vessel. An aqueous solution of uranyl sulfate is circulated through the core vessel, through an external heat exchanger where steam is generated, through a pump and back to the core. Heavy water is circulated similiarly through the annular space between the two vessels. This space is called the "blanket" space although the heavy water serves to reflect neutrons to the core.

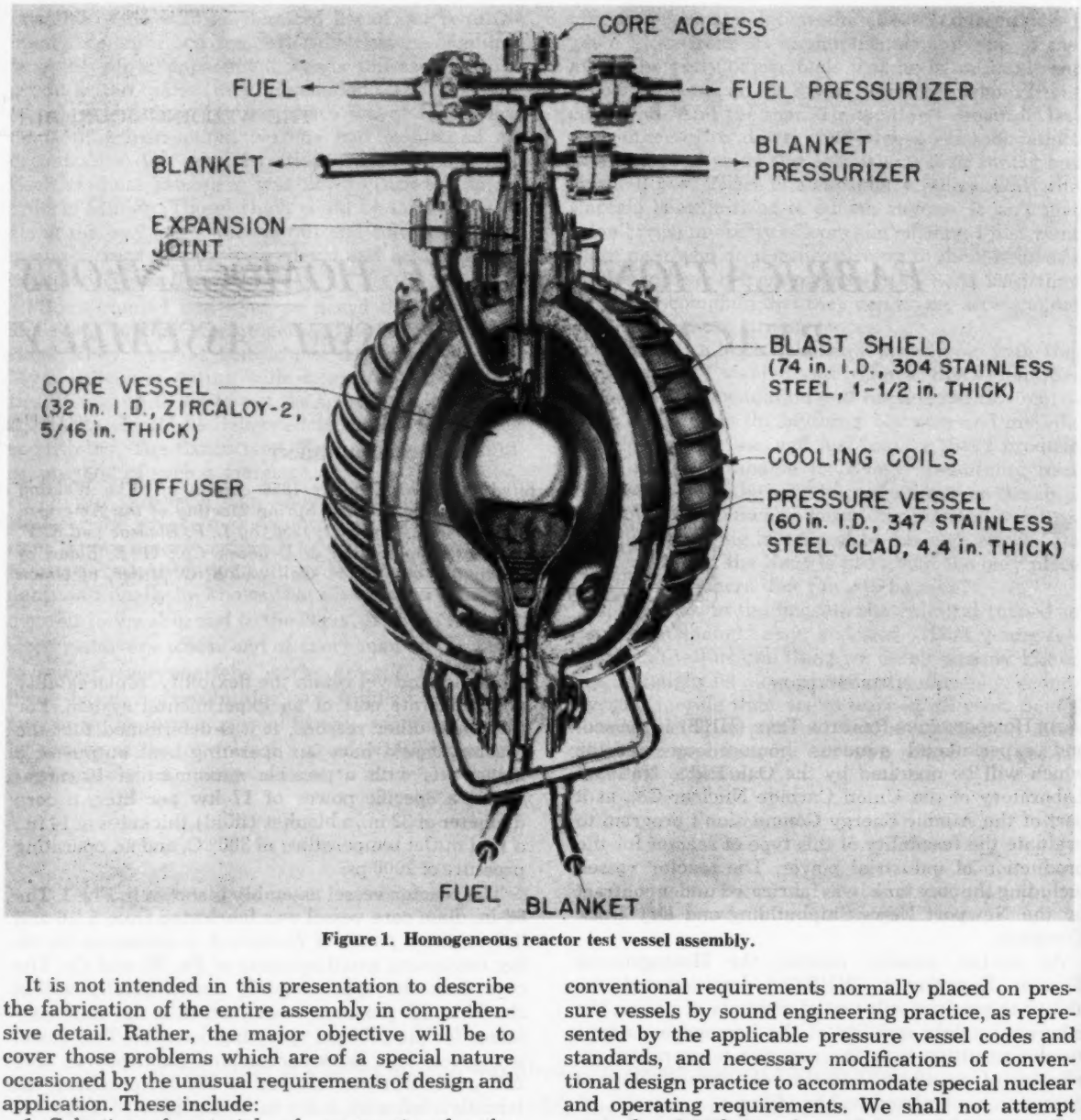


Figure 1. Homogeneous reactor test vessel assembly.

It is not intended in this presentation to describe the fabrication of the entire assembly in comprehensive detail. Rather, the major objective will be to cover those problems which are of a special nature occasioned by the unusual requirements of design and application. These include:

1. Selection of materials of construction for the pressure vessel;
2. Fabrication of the heads and nozzles and flanged end connections to the pressure vessel;
3. Development of the closure joint weld for joining the hemispherical halves of the pressure vessel shell;
4. Fabrication of the blast shield;
5. Fabrication of the Zircaloy-2 core tank.

PRESSURE VESSEL

General Considerations

The design and selection of structural materials for the reactor pressure vessel were influenced by the conventional requirements normally placed on pressure vessels by sound engineering practice, as represented by the applicable pressure vessel codes and standards, and necessary modifications of conventional design practice to accommodate special nuclear and operating requirements. We shall not attempt a complete justification here of the materials selected for the HRT pressure vessel, but some discussion is warranted regarding the factors which influenced their selection.

If neutron economy and minimum critical mass were the sole governing considerations, the ideal shape of a reactor would approach that of a sphere, but other conditions will generally dictate some modification of this basic shape. In any event, the diameter of a reactor vessel will approach the length of the vessel much more nearly than, for example, in the case of high-pressure chemical plants, where large capacities and minimum wall thicknesses of pressure containers are generally accomplished by increasing

the length, to sometimes 100 ft. or more, while keeping diameters down to a few feet or even inches. In the case of the HRT, it was possible to contain the reactor in the 5-ft. ID spherical vessel, using a Code-approved pressure vessel steel, with a 4-in. wall thickness, although even this relatively small reactor vessel created some unusual fabricating problems. As one contemplates full-scale power reactors of several hundred megawatts capacity, the size, particularly the diameter of reactors, will soon require wall thicknesses and plate sizes which will tax, if not exceed, the capabilities of current practice in the fabrication of Code-approved pressure vessel materials. In addition to the selection of a material suited to both fabrication and service requirements, consideration had to be given to other factors which are either unique to reactors or peculiar to highly corrosive pressurized systems.

Radiation Effects

The pressure vessel of the HRT will be subjected to a rather intense fast neutron irradiation. It is known that such irradiation can, under certain circumstances, produce significant changes in the properties of some structural materials, but it should be emphasized that there is no certainty that such changes will necessarily occur to a damaging extent under all conditions of reactor operation. Among these changes are increases in hardness, tensile strength and yield strength, decrease in tensile ductility, and, of particular interest in pressure vessel carbon steels, an increase in the brittle impact transition temperature, together with a possible decrease in the total impact energy resistance at temperatures above this transition. Our knowledge of radiation damage in structural materials is at present insufficient to permit prediction with complete confidence, of the ultimate performance of pressure vessel materials subjected to such radiation in operating environments. Nevertheless, we have some reason to hope that at operating temperatures, the embrittling effects of irradiation will anneal out at a rate such that a steady state condition will obtain below the danger limits for a brittle failure. In the absence of specific data to substantiate such an assumption, it was necessary to design the vessel on the basis of the worst possible conditions which might develop, whatever the opinions on the actual possibility of such an occurrence. Actually, one should probably consider the selection, design, and operations of the reactor vessel, at least in part, as a large-scale experiment to determine its radiation damage susceptibility in an environment representing a combination of all the factors existing in an operating reactor.

Thermal Stress

The high intensity of radiation incident on the vessel walls results in generation of an appreciable quantity of heat within the wall. Conduction of the heat to the surfaces of the plate develops temperature gradients in the wall. The conductivity of carbon steel is approximately twice that of stainless steel and hence thermal stresses would be roughly half as great in carbon steel. For this reason, carbon steel was preferable as the main structural material.

Materials

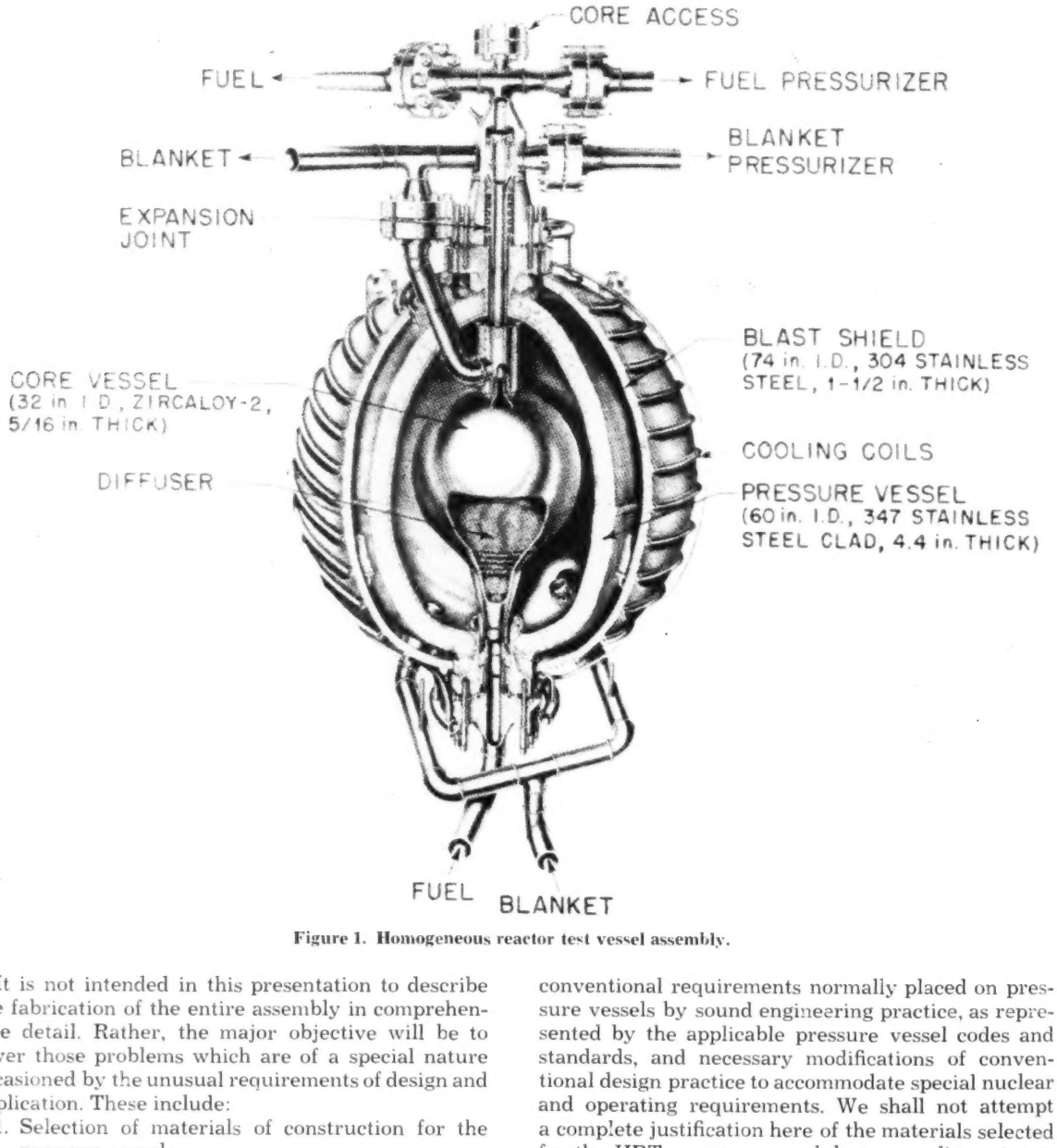
As a result of the above and other considerations, a moderately high-strength carbon steel, SA 212, Grade B, firebox quality, was selected for the principal structural component of the vessel. On the assumption—which may or may not be correct—that it should take longer to accomplish dangerous embrittlement of a steel with a lower transition temperature than if this transition temperature were higher, it was stipulated that the SA 212 material be made to fine grain SA 300 practice. The plate thickness, 4 in., required for the vessel, was in excess of that for which the steelmaker would guarantee the SA 300 low temperature impact values, but the final material actually did meet these test requirements. The carbon steel pressure shell is protected internally against corrosion by a 0.4-in. minimum thickness layer of Type 347 stainless steel, integrally clad to the base metal in the process of making the plate. The cladding, although produced to a customer specification, is essentially equivalent to SA 167, requiring a minimum of 18.0% chromium content and meeting a 0.0020 in./mo. maximum boiling nitric acid test corrosion rate in the sensitized condition.

Forming of Hemispheres

Because of the size and thickness of the heads, a combination of forming practices was required. The clad plates were heated to 2050° F and partially formed by pressing. Because of limited die size, this pressing operation affected only the center portion of the plate. These partially formed plates were reheated to 2050° F and transferred to a spinning machine in which forming started at 1950° F and continued down to 1450° F, at which point the heads were reheated and the spinning continued, three cycles being required to complete the forming. The finished formed heads were reflectoscoped to determine continuity of the bond and to check the thickness of the heads. The heads, after forming, were annealed at 1950° F, held 1 hr per inch of thickness, air cooled, annealed (normalized) at 1600 to 1650° F, held for 1 hr per inch of thickness, and again air cooled. The tensile strengths of the base metal and of the cladding after this forming and heat treatment, were approximately 78,000 psi and the shear strength of the bond was between 24,000 and 25,000 psi.

Flanges and Connections

The six nozzle reinforcements are made of SA 212, Grade B, firebox quality steel, forged by the fabricator. The various flanges, transition pieces, rings and caps, associated with the six nozzles which connect with the interior of the vessel, are Type 347 austenitic stainless steel forgings, conforming to the chemical requirements of the vessel lining. The nozzle pipes are of seamless austenitic stainless steel tubing, also of



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the modified Type 347 composition, and the 30-deg elbow nozzle pipe fitting is of substantially the same type material. Bellows pipes are of modified Type 347 stainless steel seamless tubing, and the bellows elements and tangent bands are of modified Type 347 stainless steel sheet. All of the materials for the blanket outlet baffle assembly are made from modified Type 347 stainless steel bar and forgings.

Fabrication of Heads and Nozzle Attachments

Temporary support rings and pads were welded to each head to permit handling during the fabrication of the vessel. Necessary surfaces were machined for reference purposes to permit location of the various joints, nozzles and flange faces. Nozzle openings were laid and drilled. The appropriate shell surfaces and nozzle reinforcement pads were machined for welding. The pads were then welded to the heads, after which the heads were stress relieved at 975° F for 16 hr. This stress-relief anneal is somewhat lower than normal practice, but is within permissible limits set by the Code. The lower temperature was used to minimize the possibility of sensitization of the stainless steel in the vicinity of the nozzle openings. Corrosion tests indicated that this treatment does not impair resistance of the stainless steel to general corrosion or to intergranular attack.

The joint face of each head and the face of the temporary support ring were remachined and all nozzle openings were bored and grooved to receive the nozzle pipes. The reinforcement pads were then finish faced. The stainless steel flanged nozzles which had been purchased as rough machined forgings were then premachined for assembly in the shell. The holes for pipe connections were located and drilled and the prepared ends of the pipe connections were inserted and welded into place. The pipe connections were then drilled to depth and size. The plain nozzles were cut from pipe, and shear rings, shown in Fig. 2, were built up by welding on the outside of the nozzles. The nozzles were then machined for assembly into the shell. The various nozzle, pipe and bellows assembly connections were then welded into place. In the

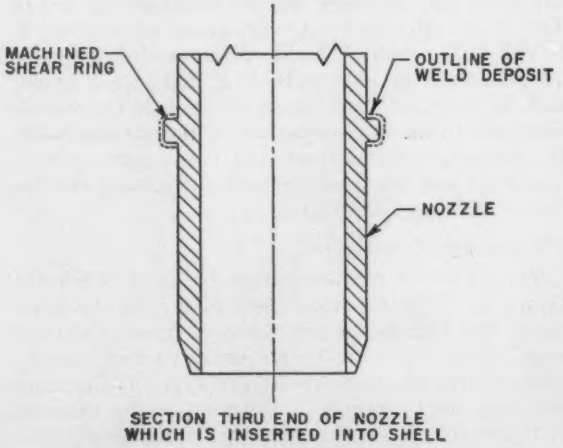


Figure 2. Sketch of nozzle shear ring weld build-up.

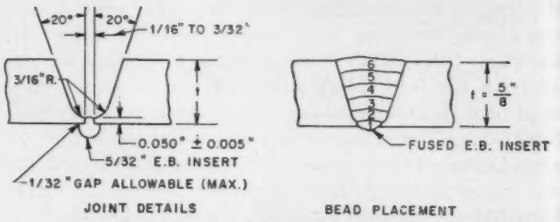


Figure 3. Welding data for 347 stainless steel.

Figure 4. Welding data for dissimilar metal joints at nozzles.

welding of the stainless steel, the inert-gas-shielded tungsten-arc process was used on all weld surfaces which were to be in contact with the corrosive process fluid. Where this surface was the root pass of a weld, a replaced consumable insert was used. Where the face of the weld was to be in contact with process fluid, the final ⅛ in. or more of weld metal was deposited by the tungsten-arc method. The manual metallic-arc process, using covered electrodes, was employed in all other parts of pressure joints and throughout all the joints in certain of the nonpressure carrying parts. The root insert and the bare filler wire conformed to A 371-53T, ER 347. Coated electrodes for the manual metallic-arc process conformed to A298-48T, class E347-15, with a minimum chrome-nickel ratio of 1.9 specified for the weld deposit. In cases where stainless steel and carbon steel were welded to each other, covered electrodes conforming to MIL-E-16715A (Ships), Type MIL-310-15 were used. In the tungsten inert-gas process, the welding current was d-c straight polarity, and d-c reverse polarity was used for the manual metallic-arc process. Inert gas protection of the internal surfaces of the stainless steel welds was provided in all cases prior to and during the welding operations. No preheat or postheat was used, and the interpass temperature was kept below 200° F. Joint details and bead sequence are as shown in Fig. 3. Those involving joints between carbon steel and stainless steel in nozzles and cladding, are as shown in Fig. 4. All joints were inspected visually prior to welding, and each completed root bead was examined visually under 20 power magnification. A liquid dye-penetrant inspection was used on the inside and outside of all finished welds after any required grinding or machining. All dye-indicated defects were repaired by grinding or chipping and rewelding. Wherever possible, all joints in pressure-carrying parts were subjected to complete radiographic inspection in accordance with the techniques of UW-51 of the Code. This was done after the first

three beads deposited in the root of the joint and also on completion of the welding and machining or grinding of the joints. No radiographic defects of any sort were permitted in the first three beads of any joint, and the completed welds were required to have no porosity, slag or other inclusions greater than size medium or in excess of half the amounts permitted by the applicable Code porosity chart.

After the installation of the various nozzles, bellows assembly, purging baffle and blanket outlet baffle, the Zircaloy-2 core tank, whose fabrication will be mentioned briefly later, was positioned in the outlet head, appropriately supported, and the inlet shell was positioned and mechanically fastened so that a 1/16-in. spacing was maintained between the two heads of the weld nose preparation. The entire vessel was then placed in the horizontal position, and both ends of the core tank were aligned concentric with the bores of the fixed flanges on the heads. The core tank outlet flange was then welded to the core tank using the methods mentioned later for the welding of Zircaloy-2. After completion of this operation the heads were separated, the core tank was positioned in its normal relationship with the outlet head, and the blanket outlet baffle was reassembled in place. The two heads were then assembled with the insert strip in place for final closure joint welding.

Since the inner surface of the closure joint was inaccessible, all welding on it had to be done from the outside. The first pass involved inert-gas-shielded tungsten-arc fusion of the preplaced Type ER 347, A371-53T insert. The weld joint preparation was as shown in Fig. 5. The bead sequence used in the procedure qualification, Fig. 6, was essentially that used in the actual welding of the vessel, with the joint divided into segments, Fig. 7. The first step involved tack welding the Type 347 insert to one of the hemis-

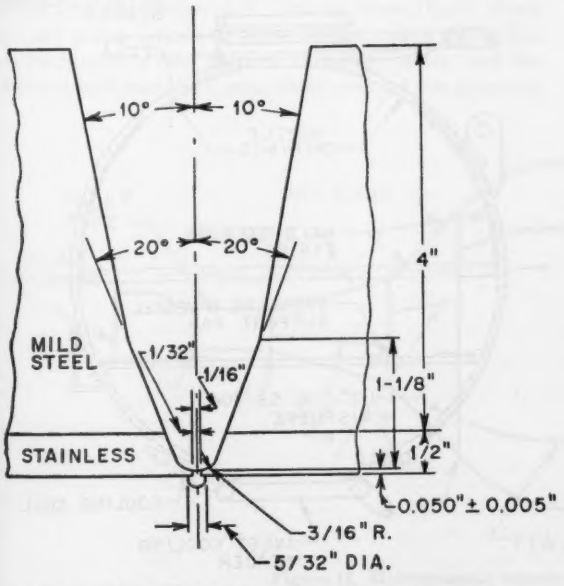


Figure 5. Weld-joint preparation for vessel closure.

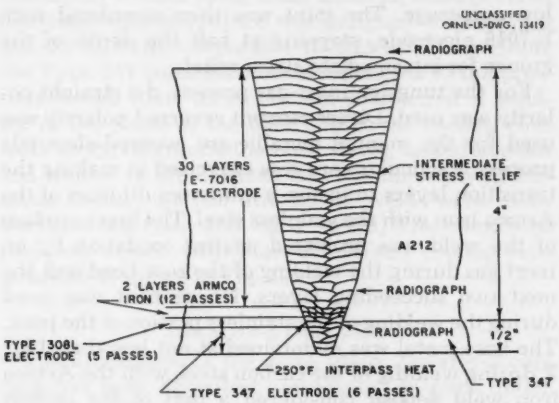


Figure 6. Closure joint bead sequence.

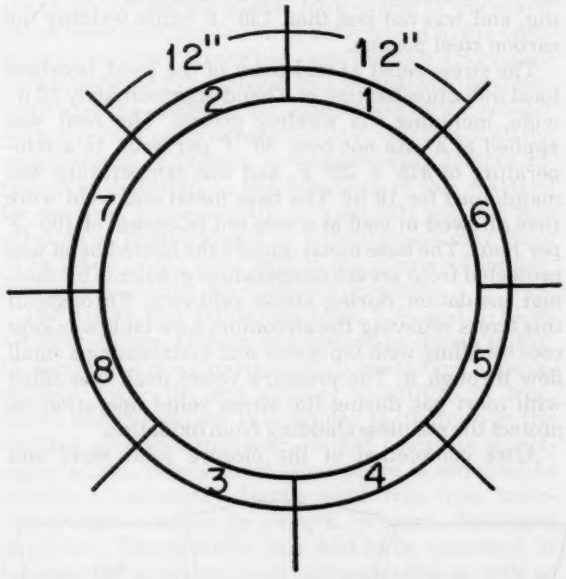


Figure 7. Pressure vessel closure joint segment welding sequence.

pheres. The hemispheres were then assembled and the insert tack welded to the other hemisphere without rotating the vessel. The welded insert was fused in block No. 1, inspected and followed with the second bead. This was repeated in block No. 2, joining the beads in block No. 1. The third weld bead followed in blocks 1 and 2. This procedure was repeated in the successive blocks of the diagram, with the vessel rotated so all welding was done from the top. In the subsequent welding, the same sequence was followed, the vessel being rotated after completion of each layer. When the 347 weld deposit was within 1/16 in. of the base metal cladding interface (passes 5 and 6), two layers or more of Type 308L electrode were deposited to build the deposit up to the interface. All indicated defects at this point were repaired. Then followed two layers (passes 12 through 23) of covered Armco iron electrode, using small stringer beads and

low amperage. The joint was then completed with E-7016 electrode, stopping at half the depth of the groove for intermediate stress relief.

For the tungsten inert-gas process, d-c straight polarity was used. Direct-current reversed polarity was used for the manual metallic-arc covered-electrode process. Particular care was exercised in making the transition layers to insure a minimum dilution of the Armco iron with the stainless steel. The inner surface of the weld was protected against oxidation by an inert gas during the welding of the root bead and the next two succeeding layers. No preheat was used during the welding of the stainless portion of the joint. The base metal was maintained at not less than 150° F during welding of the carbon steel, with the Armco iron weld deposit considered a part of the carbon steel portion of the joint. The interpass temperature did not exceed 200° F during the stainless steel welding, and was not less than 150° F while welding the carbon steel portion.

The stress relief at mid-point of the weld, involved local induction heating of a band approximately 20 in. wide, including the welding groove. The heat was applied at a rate not over 80° F per hour, to a temperature of 975 ± 25° F, and this temperature was maintained for 10 hr. The base metal and weld were then allowed to cool at a rate not in excess of 100° F per hour. The base metal outside the heated band was protected from severe temperature gradients by thermal insulation during stress relieving. Throughout this stress relieving the zirconium core tank was kept cool by filling with tap water and maintaining a small flow through it. The pressure vessel itself was filled with inert gas during the stress relief operation, to protect the stainless cladding from oxidation.

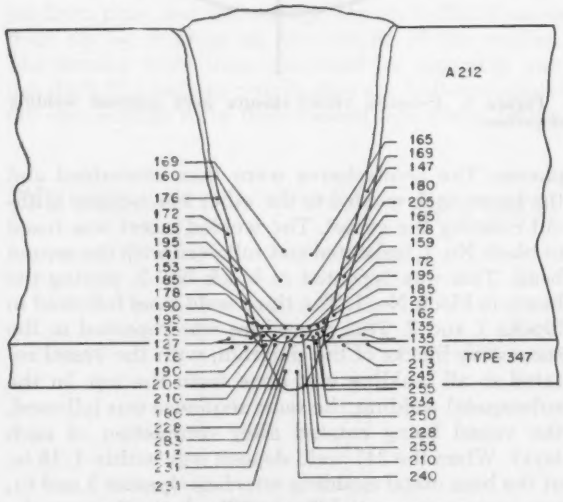
After completion of the closure joint weld and radiographic inspection, the weld and adjacent metal were given a similar stress relief, except that temporary structural encumbrances were removed in the final stress relief, and the holding time at 975° F was increased to 25 hr.

The joint was inspected visually prior to welding, and visual inspection was maintained throughout the welding operations. Completed root beads were examined under 20 power magnification. Magnetic inspections of the welds and base metal were made periodically throughout and after completion of the welding. Radiography was employed after the completion of the first three stainless steel passes, after the completion of all stainless steel welds, and after completion of the closure joint. The radiation source, cobalt-60, was located in the center of the sphere, inside the core tank, and the film to be exposed was placed on the outside of the vessel or in the weld groove. The first three stainless steel passes were required to meet the same porosity-free standards indicated previously. Subsequent radiographs were required to show no cracks, and no porosity or inclusions larger than size medium or more than half the amount allowable in the appropriate porosity charts of the Code. The completed closure joint was ultrasonically inspected before and after the final stress relieving operation.

Figure 8 shows a Brinell hardness traverse of the section of the qualification test joint.

After final stress relief, the outlet and inlet covers were assembled on the pressure vessel, all nozzles were interconnected and a hydrostatic test pressure of 4000 psi was held for one hour. The vessel was also subjected to a helium leak test.

The vessel was independently inspected by an Insurance Company Code inspector and stamped with the Unfired Pressure Vessel Code symbol.



1. Readings taken with Rockwell "A" & converted to Brinell.
2. ARMCO Iron Beads Indicated.

Figure 8. Pressure vessel closure joint procedure qualification test hardness survey.

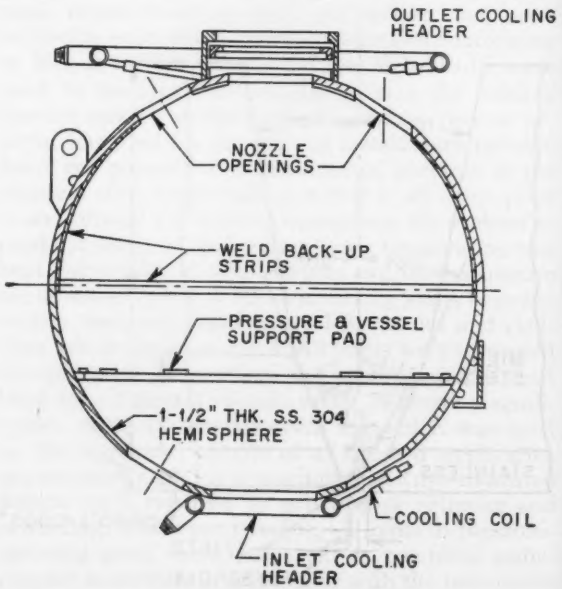


Figure 9. Sketch of blast shield.

Figure 10. HRT reactor assembly loading for shipment.

BLAST SHIELD FABRICATION

The blast shield shell was fabricated into two hemispheres by forming and welding plate segments as shown in Fig. 9. Each hemisphere consists of 6 segments and one center disk, formed from 1⅝-in. thick SA 240 plate, Grade S, Type 304 stainless steel. The top hemisphere was cut into three segments, and the entire shield was then assembled around the pressure vessel and welded using Class E308-15, A292 covered electrode. The procedure was designed to achieve a quality of weld comparable to that used in welding the Type 347 stainless steel attachments to the pressure vessel. After assembly and completion of welding of the joints of the blast shield, the cooling coils were wrapped around the blast shield, tacked in place and welded to the headers. After preliminary hydrostatic testing, the full attachment welds were made between the coils and blast shield. The completed pressure vessel, with blast shield and cooling coils attached, is shown in Fig. 10.

ZIRCALOY-2 CORE TANK

The fabrication of the 32-in. diam. Zircaloy-2 core tank has been described previously [4] in some detail, and only a brief description of the tank and welding techniques will be included here. The performance of this zirconium alloy core tank is one of the major experimental unknowns to be determined in the operation of the HRT. There has been no prior experience with a vessel of this material in a comparable environment and the schedule for completion of the reactor did not permit prior experimental evaluation of all the metallurgical, corrosion and engineering factors involved in determining the adequacy of this material for the core. Consequently, it is entirely possible that substantial modifications or substitutions may have to be made in the core tank in the course of the homogeneous reactor development program.

The vessel was fabricated from 3/8- and 5/16-in. Zircaloy-2 plate, formed and welded as shown in Fig. 11. Zircaloy-2 is a zirconium alloy containing approximately 1½% tin and smaller quantities of iron, nickel and chromium. It is similar to titanium in the welding problems involved, in that complete shielding in a high purity inert atmosphere is required to achieve a reasonably ductile weld, free from interstitial contamination by oxygen, nitrogen, hydrogen or carbon. Considerable care had to be exercised in forming the plates to avoid contamination as well as to achieve a metallurgical structure combining

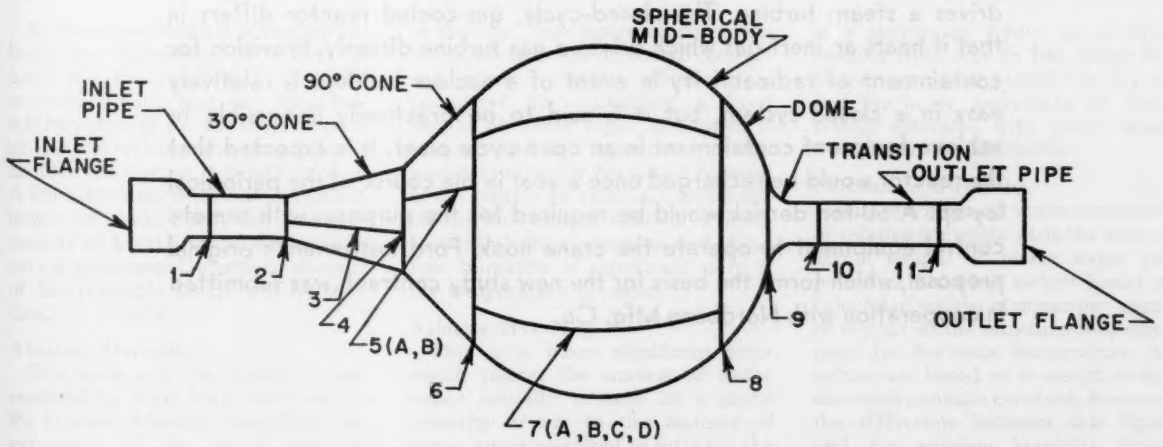


Figure 11. Homogeneous reactor test core tank sections and joints.

strength with reasonable ductility. The forming was carried out at temperatures in the alpha range, and the formed sections were given a stress-relief and recrystallization anneal at about 1200° F. The welding was accomplished by the use of the inert-gas-shielded tungsten-arc method, using helium as the primary torch gas, and a specially designed external trailing shield contoured for each joint, with provision for introducing filler metal through a quartz glass viewing window. All the operations were made as nearly mechanical as possible, the work being moved under the shield and torch during welding using a machine carriage or a weld positioner, as appropriate. Shielding gases were introduced into the shield through a diffusion chamber and distributing tubes. The root passes of all Zircaloy-2 weld joints were made using preplaced consumable inserts. Filler metal was added in all subsequent passes. All joints in the Zircaloy-2 were radiographed.

Despite the high operating pressure of the system, the differential pressure across the core tank wall is normally balanced. However, the core was designed to withstand a pressure differential external or internal of not over 300 psi in the event of fluctuations due to unusual operating conditions at temperature. The core has been pressure tested at 770 psi at room temperature.

The completed reactor vessel assembly has been delivered to Oak Ridge where it is being installed in the reactor system scheduled to begin preliminary test and operation this year.

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3. Beall, S. E., and Swartout, J. A., "The Homogeneous Reactor Test," presented at Geneva at the International Conference, Paper 526A, Sessions P. 7, P. 8, August 1955.
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Under a contract with the Maritime Administration, Ford Instrument Co., Division of Sperry Rand Corp., will make an engineering study to investigate the economic and technical feasibility of putting a nuclear powered main propulsion system using closed-cycle gas turbines into a 707-ft. long supertanker for the Maritime Administration with a capacity of 38,000 tons DW. The closed-cycle gas-cooled concept appears to offer great promise of economical power generation in the foreseeable future because it is expected to be simple, safe and to have low installation and operating costs. Most other reactor concepts now under study require the reactor to heat water or liquid metal which is then pumped through a heat exchanger. There the heat energy converts water to steam which in turn drives a steam turbine. The closed-cycle, gas-cooled reactor differs in that it heats an inert gas which drives a gas turbine directly. Provision for containment of radioactivity in event of a nuclear incident is relatively easy in a closed system, but it is said to be practically impossible to achieve foolproof containment in an open-cycle plant. It is expected that the reactor would be recharged once a year in the course of the periodical lay-up. A 50-ton derrick would be required for the purpose, with remote control equipment to operate the crane hook. Ford Instrument's original proposal, which forms the basis for the new study contract, was submitted in cooperation with Nordberg Mfg. Co.

FRANK E. CLARKE

"KEEP YOUR POWDER DRY"

THE AUTHOR

graduated from Western Maryland College in 1935 with degrees in chemistry and education. Studied advanced physical chemistry for one year at University of Maryland and taught chemistry for five years before entering the EES Chemical Laboratory in 1941. He became Head of the Boiler Water Section in 1942, Head of the Chemical and Physical Branch in 1946 and Head of the Process Branch in 1951. He has been in charge of EES development work on desiccation and dehumidification since 1946.

INTRODUCTION

DRY POWDER was a matter of life or death to the military man throughout the long period from matchlock musket to cartridge rifle. One kept his powder dry though his gun rusted, his bread spoiled with mold, and his cargo mildewed. These lesser evils were accepted as inevitable consequences of the impracticability of keeping everything dry. After all, everything could not be sealed in a can or flask and stored in the "driest place"; nor could everything be protected with rice and other homemade cures for dampness.

Time has resulted in an interesting reversal of situation. Gun powder sealed in cartridge cases of modern breech-loading weapons is much less vulnerable to moisture damage than most other military equipment. On the other hand the automatic weapon is far more liable to fail from rust than was its ancestor, the musket. Optical gunsights and binoculars cannot tolerate lens fungi spored by damp storage and tropical mildew can rot a pair of shoes or a machine gun cartridge belt.

Since many military supplies cannot be painted, oiled, or treated with vapor phase inhibitor, dehumidification (dry storage) is the only means of preserving them. During the past two decades, this process has grown from a laboratory technique, with occasional industrial application, to a large scale industry. Navy research has played a major part in its development and the Navy, like the other military services, now is reaping the benefit of longer life and better quality in military stores.

HUMIDITY—THE TROUBLEMAKER

In summer months it is common to hear the expression: "It's not the heat, it's the humidity." Virtually everyone knows that this term humidity refers to the moisture content of the atmosphere and that it has a decided bearing on personal comfort. A few additional facts will enable one better to understand the scientific aspects of humidity and dehumidification processes. Definitions of some of the principle terms will be particularly helpful.

Absolute Humidity

This term and the humidity represented by it are least significant to the layman. Absolute humidity is an expression of the actual moisture content in grains of water per pound of dry air. This figure alone means very little in terms of human comfort and other humidity effects. If a pound of air containing a fixed weight of water vapor is heated, it expands and the importance of the water is markedly decreased because of the greater air volume. Cooling the air has the opposite effect on a given amount of water vapor, so that absolute humidity is significant only if the temperature is stated.

Relative Humidity

This is a more significant term which relates the amount of water vapor actually present in a given quantity of air to the amount of water vapor required to saturate the air at the same temperature. Thus, it is a percentage figure on a scale, ranging from zero to 100, where the former represents completely dry air and the latter represents air completely saturated with water vapor, a condition we all dislike.

Percentage Humidity

This is a more accurate expression of relative humidity. It is the ratio of actual weight of water vapor per pound of air (dry weight basis) to calculated weight of water per pound of dry air at the moisture saturation point for the same temperature. All values are based on a weight of dry air which remains constant; however, the difference between this figure and the relative humidity figure generally is not important.

Dewpoint

Since lowering the temperature of the air reduces the quantity of water vapor which it can hold, it is possible to increase the relative humidity in a confined atmosphere and eventually to saturate the atmosphere with water vapor simply by cooling to the proper point. This point is called the dewpoint because the excess moisture (dew) will condense from the air if it is cooled further. This is the mechanism by which one produces fog on a cold window pane when he breathes upon it. Sudden chilling of the atmosphere at sundown produces dew and fog by the same process if the absolute humidity of the air is sufficient to yield saturation at the reduced temperature. Sweating of waterpipes and cold drink containers are other commonplace examples of reaching the dewpoint.

It is important to note that dew can be produced from air of the lowest moisture content provided the degree of cooling is sufficient. By the same token, a dewpoint can be established at virtually any temperature below the boiling point of water by properly adjusting the quantity of water vapor in the atmosphere. For these reasons it is possible for moisture condensation (dew) to form over an extremely wide range of climatic conditions.

HUMIDITY MEASUREMENT

Accurate measurement of humidity is an important factor in understanding and controlling it. Several conventional methods, but by no means all methods, are covered below.

Wet and Dry Bulb Thermometer

This is the simplest and still a widely used method of making humidity measurements. Every high school physic student will remember that a wet and dry bulb thermometer consists of two identical thermometers, one wearing a water soaked wick around its fluid bulb. Water evaporates from this wick at a rate depending on the moisture content of the surrounding air and cools the bulb in proportion to the heat adsorption attending the evaporation. Incidentally, perspiration evaporates to cool the body or remains on it to produce discomfort, for the same reason. A scale of temperature differences between wet and dry bulb readings can be converted to the approximate relative humidities.

The simple, dual bulb thermometer method is neither highly accurate nor highly reproducible because the rate of flow across the thermometer bulbs varies with the weather conditions. For proper evaporation this flow should be at least fifteen feet per second. Higher air flows make little difference but lower flows can result in insensitivity.

Sling and Fan Psychrometers

The sling psychrometer is nothing more than a wet and dry bulb thermometer unit attached to a pivoted handle so that the unit can be swirled manually to obtain higher and more uniform air flow across the bulbs. The fan psychrometer is equipped with a blower designed to circulate the optimum quantity of air across the bulbs. Figure 1 shows a wet and dry bulb fan psychrometer.

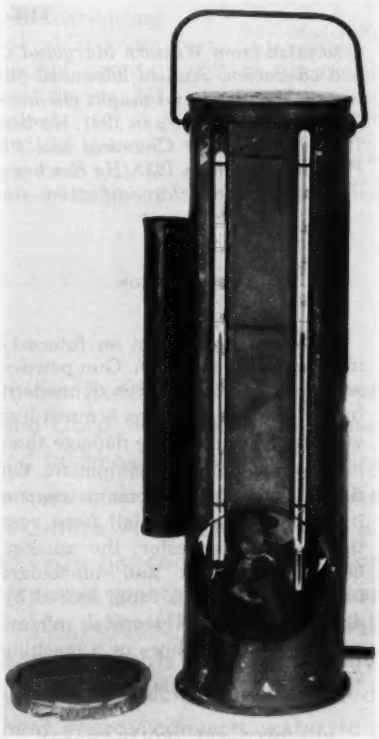


Figure 1. Fan Psychrometer.

Hair Psychrometer

This ancient and interesting device is based on the fact that animal hair will expand and contract in proportion to the moisture it adsorbs at various relative humidities. If a hair is coiled around the shaft of a needle or other indicating device and made fast at the free end, the travel of the indicator can be calibrated to read relative humidity. The humidity indicator dials of antique nautical barometers worked on this principle as did the once popular "witch and children" weather prophet. Hair actuated indicators are not as reproducible as the psychrometers discussed above and require frequent calibration.

Dewpoint Meter

This is the most fundamental and accurate device for measuring humidity. It consists of a polished mirror-surface (generally metal) with arrangements for flowing air across one side of it and a cooling medium across the other. The side of the mirror exposed to the air is viewed continuously to detect the point at which moisture condenses on the cold mirror (dewpoint or fog point) and a thermocouple or thermometer attached to the mirror indicates the exact temperature at which dew occurs. From a dewpoint temperature and knowledge of the original air temperature, one can calculate the humidity of the original atmosphere. A typical dewpoint meter is shown in Figure 2.

Dunmore Cell

This cell is the most recent widely used device for measuring relative humidity. It consists of a lithium fluoride coated noble metal spiral attached to an electrical circuit (generally 110V AC) including a microammeter. The hygroscopic coating absorbs moisture from the atmosphere until it is in equilibrium therewith and the current leakage across the spiral (bridging effect) brought about by this absorption is measured

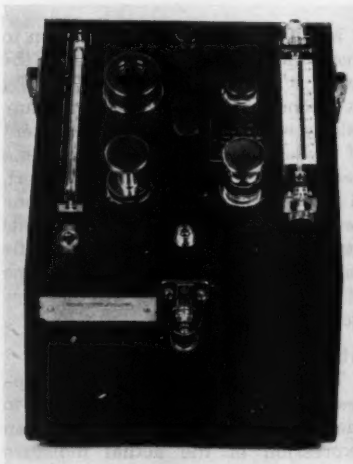


Figure 2. Dewpoint Meter.

by the increase in current flow through the microammeter. The cells are very accurate, extremely sensitive and extremely rapid in response. Simply bringing one's finger near the cell will immediately increase the relative humidity around it and increase the reading on the microammeter. A given cell covers a relative humidity range of approximately 12% so that several cells are needed to cover the entire range of atmospheric humidities. Figure 3 shows a universal selector head (full range) with elements and meter attached. Figure 4 shows one of the elements dismantled for a better view of the internal parts.

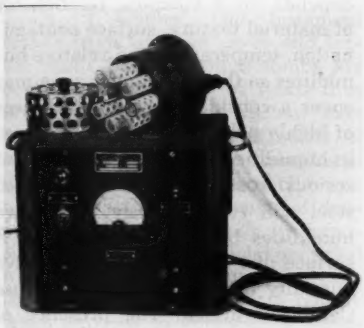


Figure 3. Dunmore Type Humidity Meter.

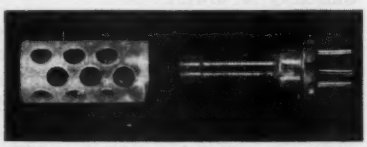


Figure 4. Dismantled Dunmore Cell.

Figure 5. Conductivity Type Moisture Meter.

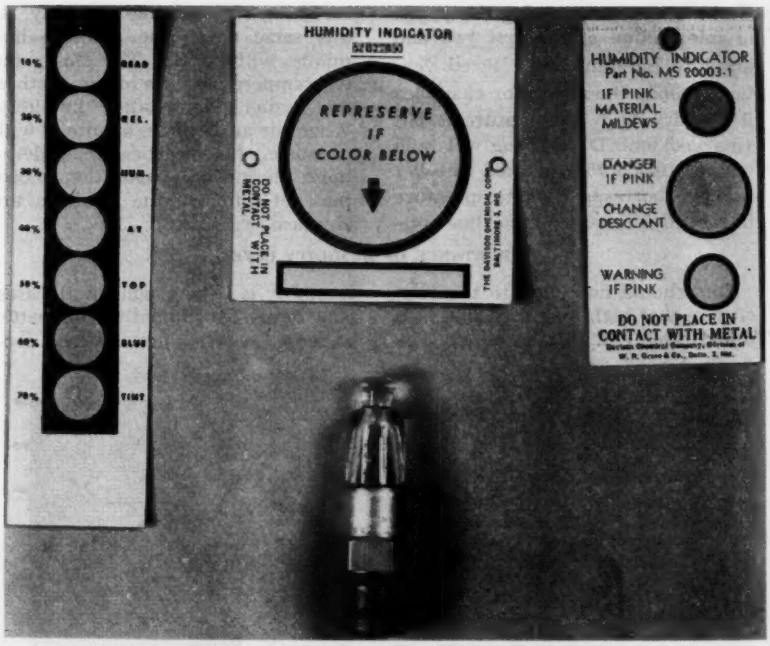


Figure 6. Color Type Humidity Indicators.

Other Humidity Indicators

While the above are typical devices for measuring humidity, they by no means include all possible variations. Other devices are used, particularly where small size of sensing element is important and where rapid response and high sensitivity are unnecessary. Figure 5 shows one such device. Its small sensing element consists of a tiny piece of porous wood or other moisture adsorbent which completes a circuit between two electrodes attached to a meter and power source. The principle is roughly similar to that of the Dunmore cell but the element's response is considerably slower. The advantages of this element are extremely small size and the fact that it is virtually indestructable in package applications.

Colorimetric Humidity Indicators

These indicators are based on the fact that certain chemicals have different colors in hydrated and dehydrated forms. For example, cobalt nitrate is blue when dry and pink when wet. Paper cards and drying agents impregnated with it will show the same color extremes and yield a series of transition shades at points between them. Thus they can be used to show extent of water adsorption which is a function of relative humidity.

Unfortunately, the color indicators are not highly sensitive, highly reproducible, nor completely reversible. The moisture sensitive chemical can be leached out by condensation at the dew point and other atmospheric contaminants, like hydrocarbons, can alter colors. At best, they are only rough indications of desiccant quality and atmospheric humidity. Nevertheless, color indicator materials frequently are used as tell-tales in dehumidified compartments. Figure 6 shows typical humidity indicator cards and a "Humiplug." The latter is placed in spark plug openings of stored engines to indicate relative humidity in the cylinders. The plug contains an adsorbent (silica gel) impregnated with a moisture sensitive colored salt.

INTERPRETATION OF HUMIDITY READINGS

When a psychrometer or dew point meter is used in measuring atmospheric moisture, an appropriate chart or table is needed for converting to relative humidity. These charts, commonly known as psychrometric tables, vary in specific details, but all are based on the same physical principles. A typical chart is shown in Figure 7. Dry bulb temperatures are listed across the bottom, wet bulb temperatures run obliquely from upper left to lower right, relative humidity lines are

shown as curves crossing the points of intersection of the first two and absolute humidities are listed vertically along the right. For example: if the dry bulb temperature is 80° (marked with D) and the wet bulb temperature is 75° (marked with W) the two corresponding temperature lines will intersect on the line representing 80% relative humidity. At this same point, the absolute humidity will be 123. The closer the two temperatures are to one another, the higher the relative humidity. When the air becomes saturated with moisture, for practical considerations, there is no evaporation to cool the wet bulb, so the readings are identical.

IMPORTANCE OF HUMIDITY LEVEL

One should not jump to the conclusion that high humidity always is undesirable and that extremely low humidity is to be sought in all cases. The lower the humidity the better as far as corrosion prevention is concerned. However, low humidities can have deleterious effects on other materials like leather, certain plastics, and paper, which tend to become extremely brittle if completely dehydrated.

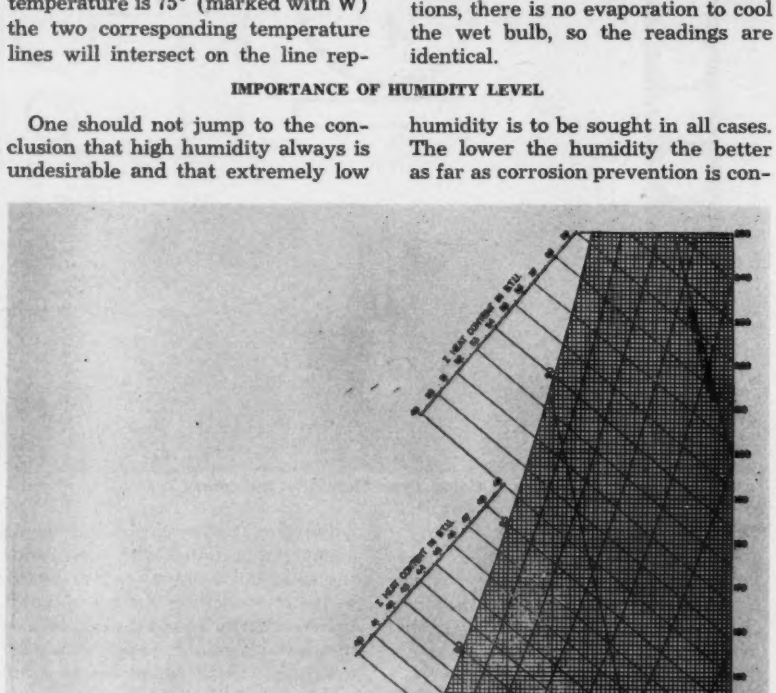


Figure 7. Psychometric Chart.

Consideration of the above factors as well as the economics of reducing moisture content have led most investigators to agree that a relative humidity of 30 to 40% is reasonably safe as far as preservation of materials is concerned, but even this is not always true.

The absorption of dangerous quantities of moisture on metal surfaces depends on a complex relationship of material texture, surface contamination, temperature and relative humidities so that the danger zone may cover a considerable range. A piece of highly polished steel can be stored in humidities as high as 80% without serious rusting, while sandblasted steel will rust seriously at relative humidities between 40 and 50%. If surface dirt is present, 20% relative humidity may be sufficient to cause significant attack. The presence of hygroscopic salts such as sea salts and residues of fingerprints can cause surface etching down to 10% relative humidity or lower.

Objectionable humidity effects below the moisture saturation point do not depend on the dewpoint phenomenon, but rather on capillarity and hygroscopicity. Rough surfaces contain innumerable pores or capillaries which can absorb moisture from unsaturated air and deposit it as monomolecular or polymolecular films, depending on the relative humidity and the size of the capillary. When a proper relationship exists between corrosion sensitivity of the metal, temperature of the atmosphere, and quantity of water deposited, corrosion will occur. Hygroscopic materials can complicate the picture by absorbing water chemically and generating corrosive solutions. Time also is an important factor. Temperature fluctuation in the atmosphere causes the humidity to rise and fall as previously mentioned. Mechanisms like hygroscopic absorption and capillarity involve appreciable time, so short periods of high humidity may not cause damage.

Since excessive moisture is a cause of many ills, drying is the logical corrective treatment. Drying can be directed primarily at either the material in question or its surrounding atmosphere. The first process generally is called dehydration or desiccation, while the latter is known as dehumidification. If continued long enough both processes eventually can eliminate moisture completely from item and surroundings; however, their basic objectives are rather different as shown below.

Dehydration—An Ancient Art

Preservation by dehydration has been known and practiced since the dawn of history. Old testament scrolls from Galilean caves and fertile seeds from Egyptian tombs are conspicious examples of items thus preserved by nature. Ancient man undoubtedly learned the merits of the process from similar examples of natural preservation in arid climates.

True dehydration consists of drying an item so completely by exposure to sunlight or artificial heat that it will neither readily support organisms of decay nor rehydrate readily when exposed to atmospheric moisture. Dried fruits, powdered milk, jerked beef, and hard tack are examples of dehydrated foods.

Dehydration tends to remove volatile material other than water so that rehydrated items generally are not equivalent to their originals in every respect. This process alone will not guarantee freedom from corrosion and fungus which can be sustained by atmospheric moisture as well as original moisture content of the material. Brittleness from complete absence of moisture is another disadvantage of dehydration.

What is a Desiccant?

Virtually every solid material is a desiccant (drying agent) in some degree. Most of them dry by physical adsorption of water or water vapor and their water adsorption capacities generally increase with increase in relative humidity of the surrounding atmosphere. The curves in Figure 8 show to what extent the water adsorbed by each material depends on relative humidity. The material at the top of the graph (silica gel), is the only one recognized as a modern commercial desiccant. Less adsorbent surfaces like glass, would have curves even lower and flatter than that of rubber.

DESICCATION

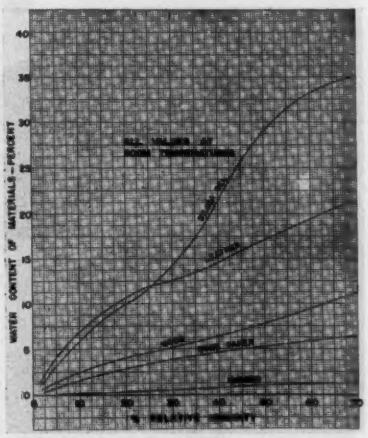


Figure 8. Bulk Moisture Adsorption Characteristics.

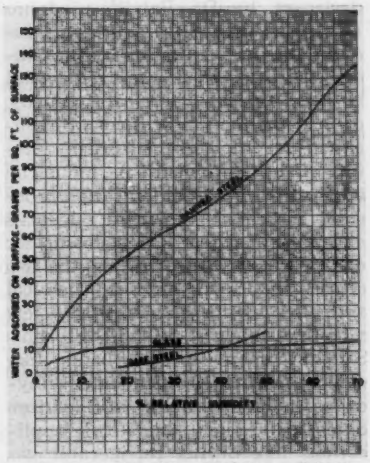


Figure 9. Surface Moisture Adsorption Characteristics.

Figure 9 shows surface moisture adsorption characteristics for bare steel, painted steel, and glass. It is interesting to note that the relatively low adsorption capacity of glass is rather independent of variation in atmospheric humidity.

Physical desiccants of the type depicted in Figures 8 and 9 do not adsorb all moisture from their surroundings but establish equilibria in which part of the water is retained by the desiccant while part remains in the atmosphere. Practically all of them retain more moisture at high humidity than at low humidity. This equilibrium type of adsorption distinguishes physical desiccants from chemical types.

Chemical desiccants like time honored quick lime and calcium chloride, continue to absorb water until they are saturated completely or until all moisture has been absorbed from the surrounding atmosphere. These materials generally form chemical compounds with the water absorbed (hydrates) and many of them even dissolve in the water absorbed. The water content of a saturated chemical desiccant does not fluctuate markedly with change in atmospheric humidity. Frequently, such materials cannot be regenerated to their original conditions. This is in contrast to physical desiccants which generally are easy to regenerate.

Pioneer Desiccant Applications

One can find scattered examples of the use of drying agents back to ancient times, but the real dawn of industrial desiccation, particularly physical desiccation, dates back only to about the first quarter of the twentieth century. Prior to that time, laboratory drying of test samples in sealed glass containers known as desiccators and occasional industrial applications of quick lime and calcium chloride were the major applications. It is interesting to note that many early industrial applications of physical desiccants in this country were not concerned primarily with prevention of rust, mildew, and rot, but with miscellaneous uses like the examples below.

EARLY USES OF COMMERCIAL DESICCANTS

a. Drying gases in mechanical refrigerators.
b. Drying carbon dioxide in dry ice industries.
c. Drying air intake to blast furnaces.
d. Drying internal atmospheres of telephone cables.
e. Desiccating breathing air for pneumonia patients.
f. Lining plaster casts to prevent skin itch from perspiration.
g. Preparation of toothpaste and toilet powders.

The Navy made one unusual and spectacular early application of physical desiccant during this period by installing moisture absorbers on the air lines of divers working on the sunken submarine, S-4. This was a precaution against fouling of the air lines with frost.

Modern Commercial Desiccants

While industrial desiccation got off to a slow start, it was destined to rapid expansion. Discovery of silica

gel, or at least its application as a desiccant, by Dr. Patrick of Johns Hopkins University and related industrial experimentation by the Silica Gel Corporation, organized in 1921 by the Davidson Chemical Company, opened up many new fields of application for moisture adsorbent materials and equipment. As industrial application of dehumidification processes increased, desiccant materials appeared to meet the demand for drying agents. These fell into the two classes mentioned earlier, chemical and physical adsorbents, with a few members hovering on the borderline. Straight chemical absorbents like calcium chloride, quick lime, anhydrous calcium sulfate, and barium oxide found many small-scale applications like drying refrigerator gas and laying up of idle boilers, but they never broke into the real large scale static and dynamic drying business. Eventually they were supplemented with or superseded by other chemical absorbents including several synthetic materials. The calcium chloride impregnated diatomaceous earth and charcoal shown in Figure 10 are examples. The third material shown in Figure 10 is a rather unusual type of chemical desiccant, calcium carbide. This absorbs moisture by the carbide-water reaction, $CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$, which generates acetylene gas and calcium hydroxide (hydrated lime). This is neither physical adsorption nor chemical absorption (crystal hydration) in the usual sense. Desiccation with calcium carbide is limited to applications like refrigerator drying, where release of acetylene gas is not an explosion hazard.

From the standpoint of quantity used, the physical adsorbents are far more important than the chemical absorbents mentioned above. The earliest of these to gain popularity was silica gel. Several varieties are shown in Figure 11. This is produced by reaction of sodium silicate and sulfuric acid to form hydrated silicic acid. The resulting gel is dehydrated in such a manner that a glassy silicate of extremely high porosity is obtained. This material is chemically inert, relatively high in adsorption capacity, and readily regenerable (by heating) for continued use. If properly made it is not corrosive even when saturated with moisture and it will not become wet with its own adsorbed water. It is suitable for dynamic (air circulation type) or static (package type) dehumidification.

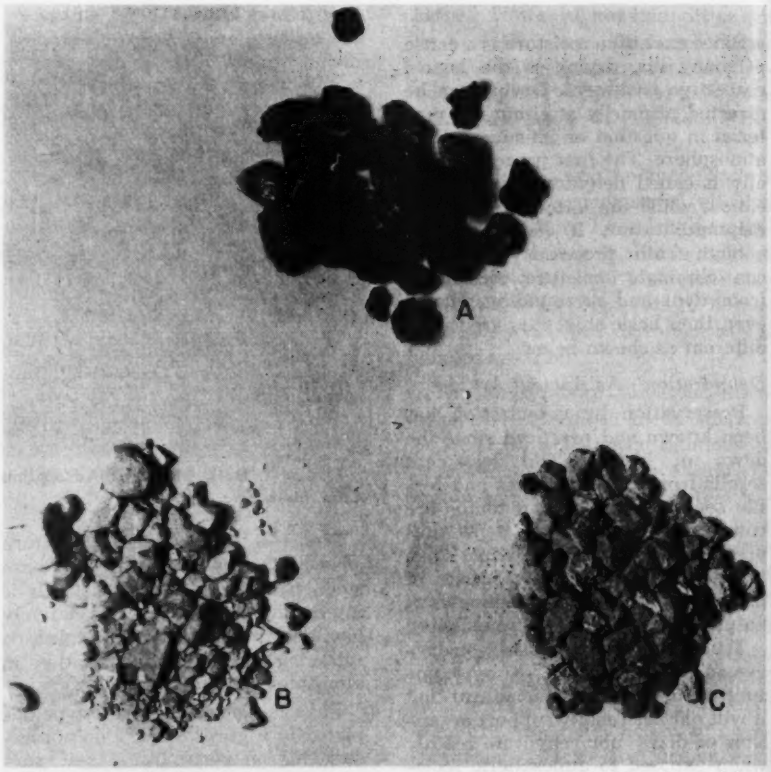


Figure 10. Chemical Desiccants: (a) Charcoal + Calcium Chloride; (b) Calcium Chloride + Diatomaceous Earth; (c) Calcium Carbide.

Item (a) of Figure 11 is granular silica gel, the earliest and most common type. Item (b) shows similar silica gel impregnated with cobalt nitrate, which turns pink when hydrated and blue when dry, thus indicating its drying capacity. Item (c) is an interesting spherical form of silica gel originally developed for catalytic work in the petroleum industry, rather than for desiccation. The last is extremely tough and dust free which makes it ideally suited to applications where dust is objectionable.

Figure 12 shows samples of montmorillonite, a natural clay, (a), granular and spherical aluminas (b) and (c), and bauxite (d). All are physical type desiccants. Material (a) has higher moisture adsorption capacity than silica gel at low humidities (below 30% relative humidity) and lower capacity at higher humidities. The remaining materials have lower adsorption capacities at all humidities. All of them can be regenerated repeatedly.

DYNAMIC DEHUMIDIFICATION

This type of drying was the first to invade the field of material preservation on a large scale. In principle, it consists simply of passing the air stream to be dried through a filter bed or cartridge of desiccant and either discarding or regenerating the desiccant periodically on the basis of a predetermined time cycle or a humidity test on effluent air. Simple expendable drying cartridges were used in the first dynamic dehumidifiers, but cost considerations led to dual-bed machines with automatic gear for operating one bed in the adsorption cycle while the other was regenerated with internal heaters and exhaust fans. The Navy used large numbers of these machines in mothballing the Fleet at the end of World War II. An example is shown in Figure 13. It was designed for cperation on either a time cycle or an automatic hygrometer control, depending on the application.

The moth-balling operation consisted of first sealing the various ship compartments as nearly as possible against atmospheric leakage and then connecting them to a number of dehumidifying machines by a maze of ductwork. Figure 14 shows a naval

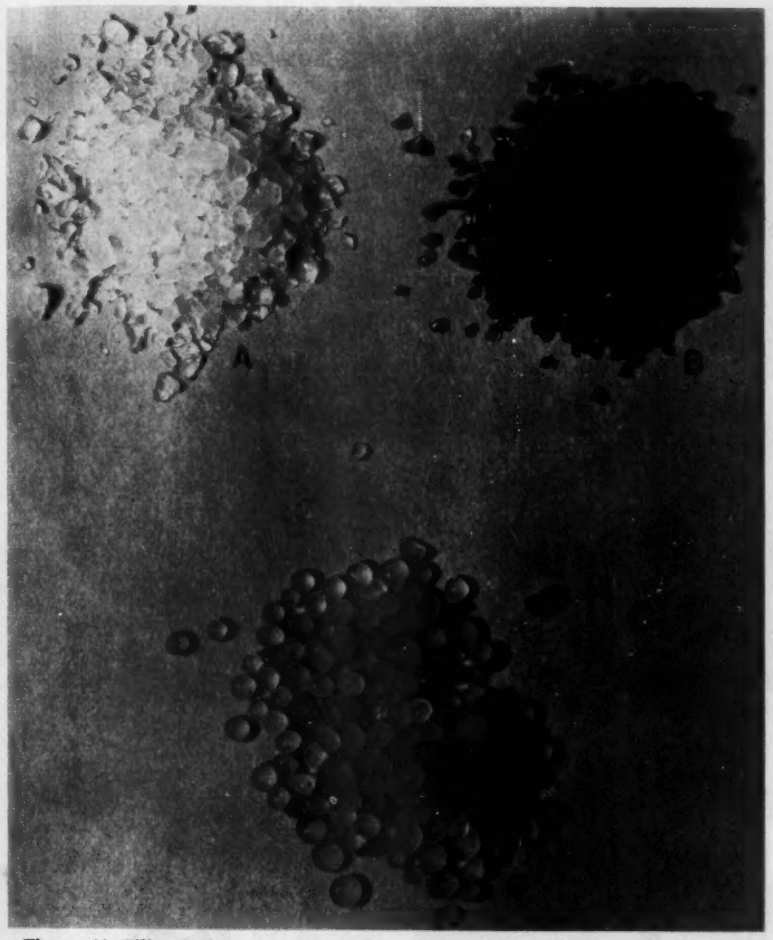


Figure 11. Silica Gel Desiccant: (a) Granular; (b) Color Impregnated Granular; (c) Spherical.

vessel being reactivated from mothball status. The dome-like caps on the deck are sealed covers over gun turrets dehumidified by the dynamic process described above.

Innumerable other applications of dynamic dehumidification are used in conjunction with Naval machinery. For example, dual-bed machines are used for reducing moisture content and freeze-up problems in liquid oxygen plants of aircraft carriers. Warehouses in supply depots sometimes are dehumidified in the same manner.

The above should not be misconstrued to mean that the dual bed desiccant machines are the only means by which dynamic humidity control can be effected. Many domestic dehumidfiers and commercial air conditioners operate on the freeze-out or condensation principle of cycling the air through refrigerated coils and condensing or freezing the water vapor at that point. These processes generally are incapable of reducing humidity to extremely low levels and are used for personal comfort (medium humidity range) rather than for preservation uses.

STATIC DESICCATION (METHOD II PACKAGING)

Today, this type of material preservation probably is more important than dynamic dehumidification. It is somewhat more complex in theory and application and consequently is a continuous source of research and development problems. Stepwise, government method II packaging of large items consists of cleaning the item, fastening it to a pallet or skid covered with a moisture resistant barrier, tying bags of desiccant at appropriate points on the equipment, sealing the whole with a moisture vapor proof envelope, covering the envelope and the pallet with a wooden crate and finally sealing the crate in a moisture resistant coating like tar paper. Figure 15 shows an item in place on the pallet with desiccant bags in place and the moisture proof envelope open. Figure 16 shows heat sealing of the envelope and Figure 17 shows the finished package with external crate in place.

The theory of package desiccation is obvious. The desiccant adsorbs water from the item and the package atmosphere and the barrier prevents entrance of outside moisture. This is the ideal situation not always realized.

If padding (dunnage) is required to prevent rattling of the contents of a Method II package a variety of materials can be used for the purpose (see Figure 18). The rubberized hair and felt (a) and (b) and the paper and glass fibers (c) and (d) are typical examples. The moisture adsorption characteristics of these materials are important since they add to or detract from the absorption load on the desiccant. Glass and rubberized products are relatively non-absorptive, as previously shown, and consequently can be used without special care. Old time dunnage materials like paper and excelsior must be dry for safe use.

Not all Method II packages require the heavy base pallet and external crating shown in the examples. Smaller items can be packaged in appropriately smaller and more fragile containers, however the basic principle of anchoring the contents, distributing the desiccant, enclosing the package in a moisture-proof barrier and covering the whole with a protective shell are common to the process.

Interesting variations of package desiccation include the packaging of airplane engines in desiccated hermetically sealed cans and cocooning desiccated equipment with sprayed plastic, web-like coverings.

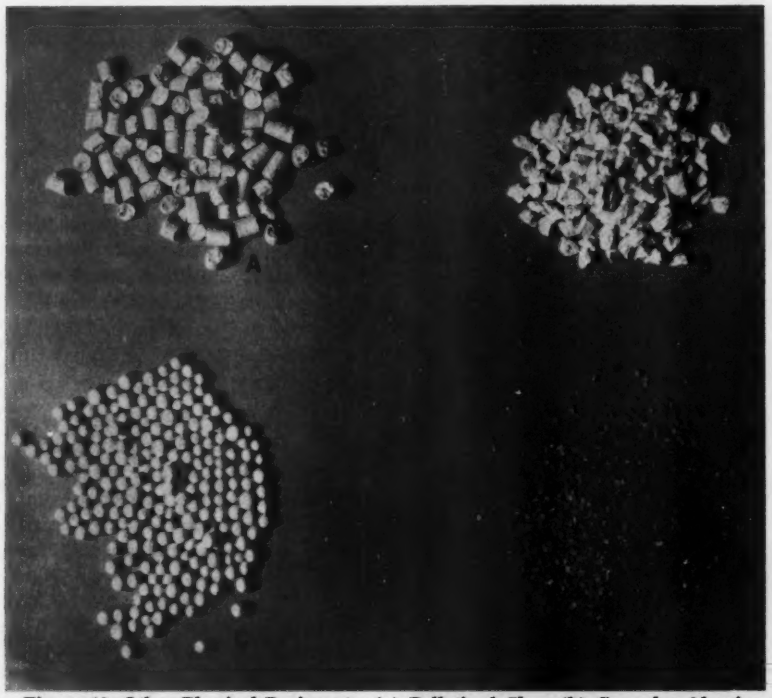


Figure 12. Other Physical Desiccants: (a) Pelletized Clay; (b) Granular Alumina; (c) Spherical Alumina; (d) Bauxite.

changes which causes them to occur. A typical lag loop plot is shown in Figure 19. The oblique lines represent constant dry bulb temperatures. The point at the lower right hand corner of the roughly circular loop shows that the package atmosphere was at 46° F. (dry bulb), 24° F. dewpoint and 41% relative humidity at 6 a.m. Following this line to the left shows that the temperature gradually increased until 8 a.m. and then increased sharply to noon. After this point it increased more slowly to 6 p.m. and then declined to 6 a.m. the following day, completing the cycle. During the upward climb, relative humidity decrease lagged behind temperature increase and the opposite occurred during temperature decline. The lowest humidity occurred at noon and the highest occurred at 4 a.m. as might be expected. However, the dewpoint was not reached in any case so that no moisture condensed in the package because of temperature change.

Lag loops are bound to occur in any package subjected to appreciable temperature changes. If stored outside so that exposure to direct sunlight increases temperature rapidly

PROBLEMS IN METHOD II PACKAGING

Lag Loop Phenomenon

A number of factors complicate Method II packaging beyond the simple process of sealing desiccant and equipment in a moisture proof envelope. Weather changes within the enclosed atmosphere are a major source of concern. These occur regardless of the presence of most desiccants because of the lag loop phenomenon. This term is used to describe the tendency of moisture variation (absorption and desorption) to lag behind the temperature

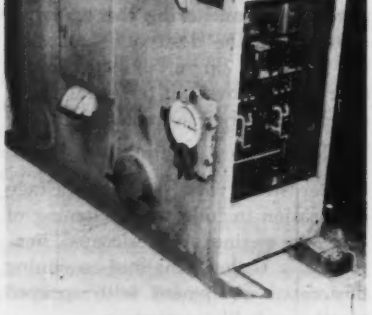
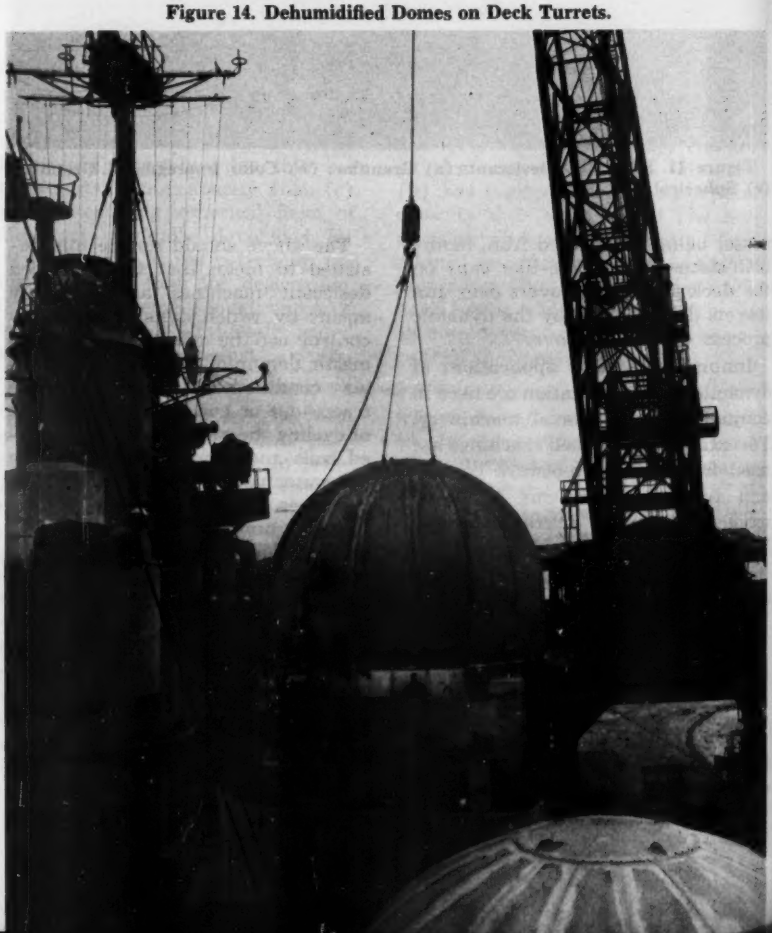


Figure 13. Dynamic Dehumidifier.

Figure 14. Dehumidified Domes on Deck Turrets.



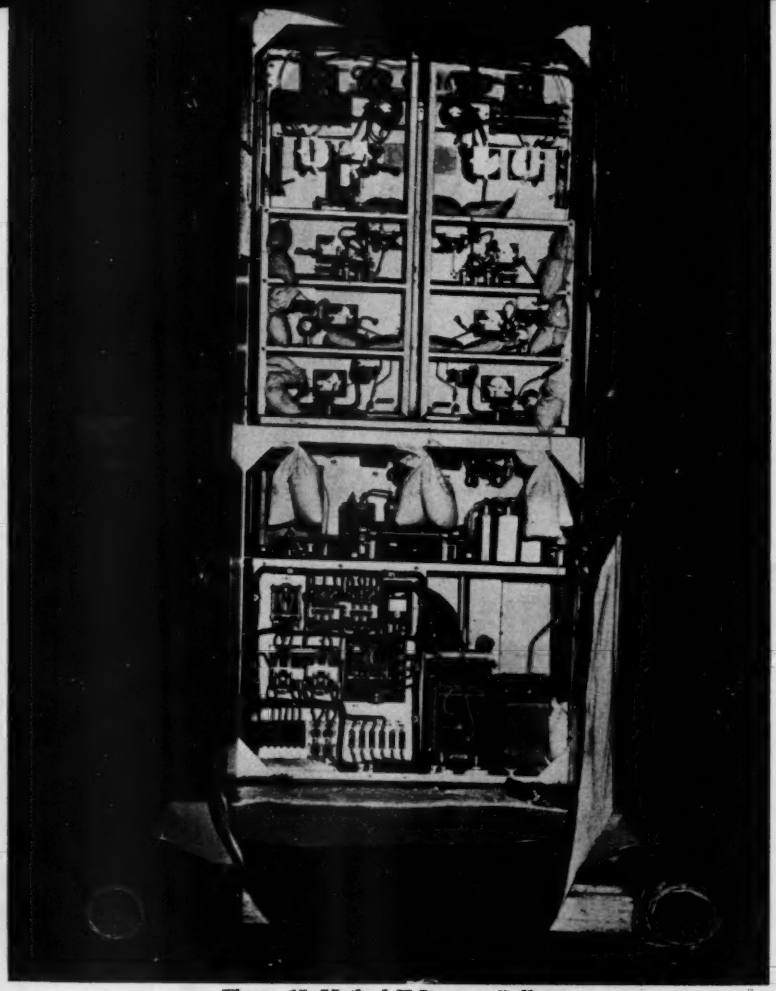


Figure 15. Method II Item on Pallet.

during the day, the swings will be greater and the lag loop larger. If the package is well insulated or stored inside, the loops will be correspondingly smaller. In either case, the moisture adsorption rates of the desiccant, and the dunnage, and the total quantity of desiccant present will affect the size of the lag loop. The lag loop should never dip below dewpoint temperature, nor should it remain above recommended humidities for long periods of time. Within these limitations the average relative humidity represented by the loop can be accepted as the relative humidity for the package in question.

Package Breathing

Unless a package is absolutely airtight (hermetically sealed) it is bound to breathe by inhaling a small amount of air on cooling and discharging it on heating. The smallest perforations, crevices, and pores in the moisture vapor barrier will allow this breathing if temperature changes are great enough to cause significant pressure differentials. In some cases of outside storage, where extreme temperature changes make breathing particularly severe, desiccated solar breathers have been used to minimize the effect of introducing outside air. A typical solar breather is illustrated in Figure 20. It is simply a black container of desiccant through which the air must pass on entering or leaving the desiccated package. Because of its color, the solar breather heats more rapidly than the package so that air expanding from the latter in the heat of the day passes through the warm desiccant bed and partially regenerates it (drives off moisture). At sundown, the breather cools rapidly because of its better conductivity characteristics and absorbs moisture from the air which enters the main package as it cools and its atmosphere contracts. It must be remembered that the solar breather simply reduces the amount of moisture picked up by the breathing package and that it does not eliminate it altogether. Obviously such a breather is most useful in outdoor storage.

Desiccant Placement and Convection

The amount of desiccant sealed in a Method II package is based on the estimated total moisture content of the atmosphere, contents, and dunnage, and the assumption that adsorption will not be hindered by problems of desiccant placement, and air circulation. This often is a dangerous assumption. The working

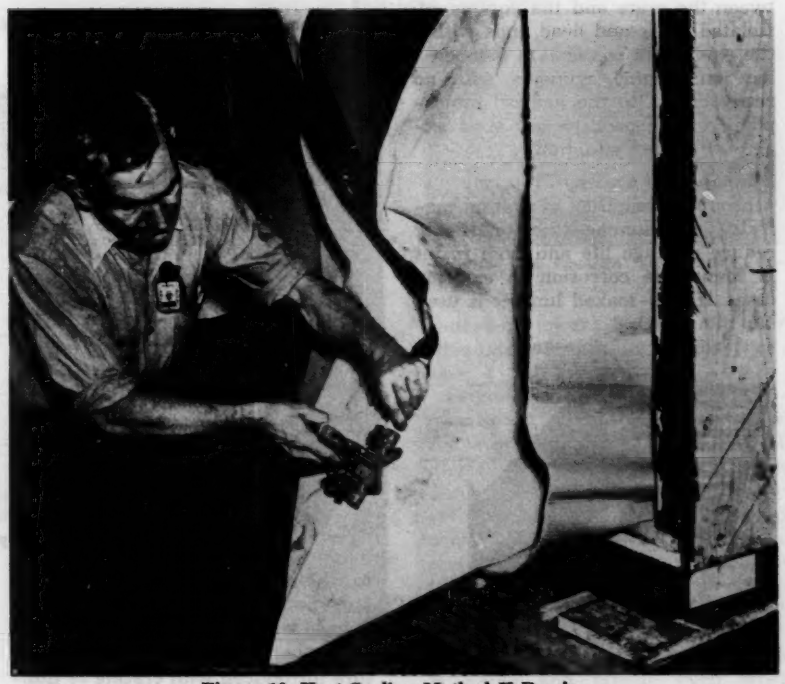


Figure 16. Heat Sealing Method II Barrier.

Figure 17. Crated Method II Package.

table of a packaged drill press can act as a barrier to air circulation and prevent proper desiccation of the top of the package if all of the desiccant is placed at the bottom. Furthermore, if the desiccant is placed at the bottom of any package, natural convection tendencies oppose distribution of desiccated air which is heavier than humid air.

In addition to circulation barriers resulting from improper spacing between the crate and the equipment, isolated voids and dead ends within the equipment can lead to poor desiccation. Engine cylinders with no ready access to the general atmosphere of the package are good examples of this situation.

Dunnage and Crating Problems

Improper handling of crating material and dunnage can markedly reduce package life and even result in immediate corrosion in extreme cases. If rain-soaked lumber is used

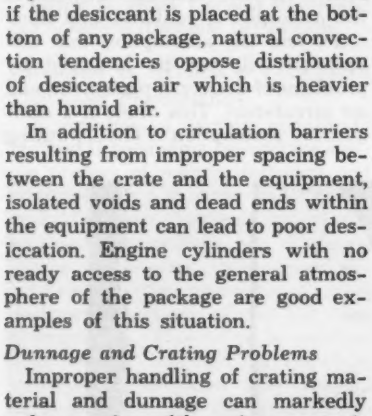


Figure 20. Desiccated "Solar Breather."

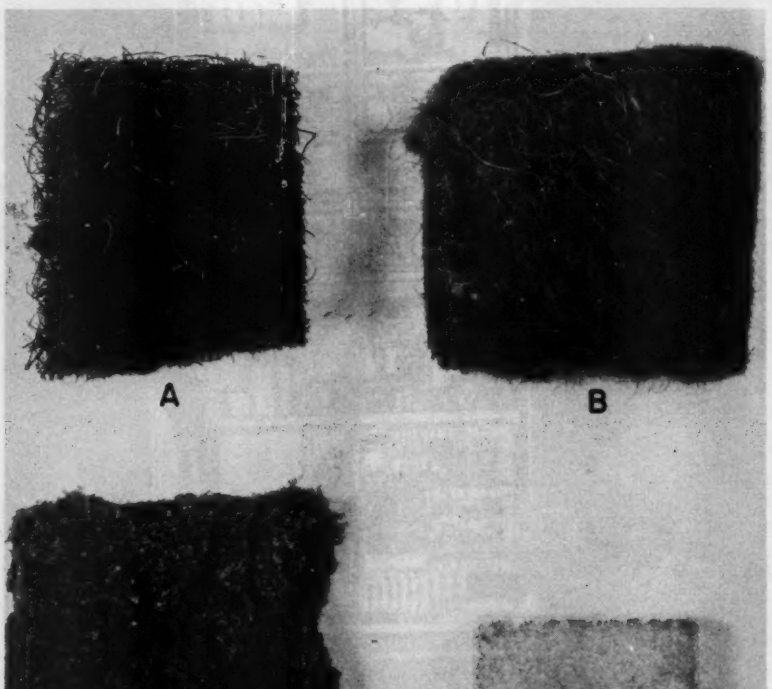


Figure 18. Dunnage Materials (Method H): (a) Rubberized Hair; (b) Felt; (c) Paper; (d) Glass Board.

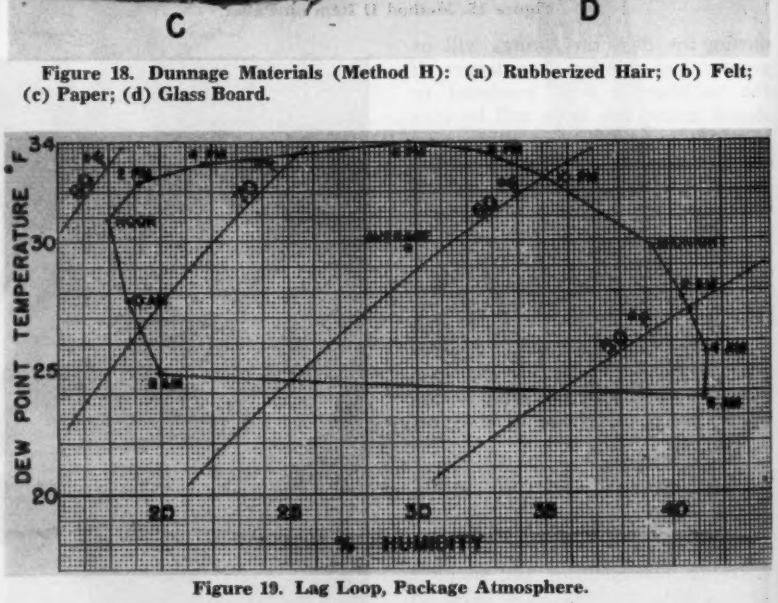


Figure 19. Lag Loop, Package Atmosphere.

for the crates, the desiccant capacity may be used in adsorbing this abnormal water instead of that from the atmosphere. Any unnecessary moisture introduced with crating or dunnage is money down the drain, just as dry packaging material is added protection.

Desiccant Dust

This is a very serious problem particularly in Method II packaging of delicate instruments. Most desic-

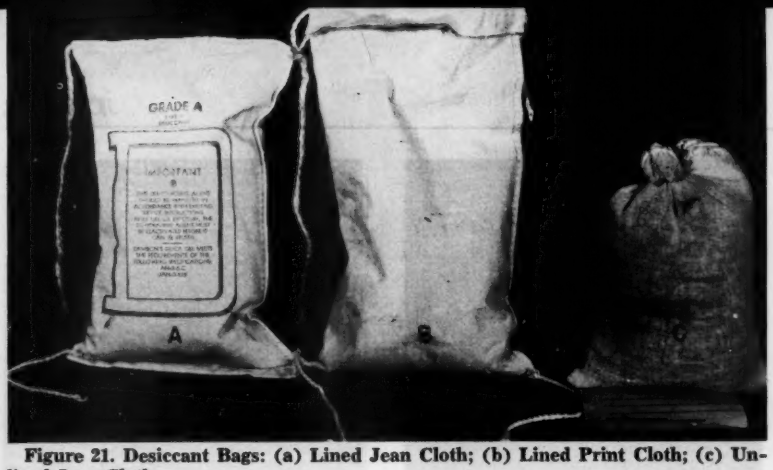


Figure 21. Desiccant Bags: (a) Lined Jean Cloth; (b) Lined Print Cloth; (c) Unlined Jean Cloth.

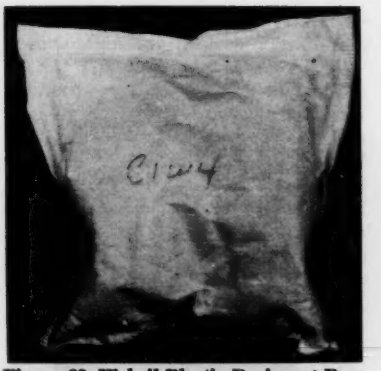


Figure 22. Webril Plastic Desiccant Bag.

cant materials are inorganic substances which are somewhat abrasive and sometimes slightly corrosive. If the desiccant is not completely isolated from the contents, its dust can sift into the vulnerable parts and render them inoperative. Instruments thus affected may perform for a short period and then fail at a critical time. Even if dust is observed on removing the crating, dismantling and cleaning the equipment is a tedious, time consuming job frequently beyond the capability of field personnel.

DESICCANT BAGS FOR PACKAGE DESICCATION

Many of the afore-mentioned problems of package desiccation revolve around the desiccant bag. A good desiccant bag must minimize dusting, transmit moisture rapidly to reduce lag loops, resist perforation in rough handling and remain strong and pliable despite long period desiccation.

The paper-lined jean-cloth bag in Figure 21 was among the first used for large-scale package desiccation. This had sewn seams and tie-strings at one end for fastening it at strategic places within the package. While this bag was used with reasonable success throughout World War II and still is in use, it has several disadvantages. The paper-liner tends to crack and crumble particularly after it is thoroughly desiccated by the contents. The sewn seams vary in dust integrity, depending on the quality of the sewing machine, size of thread, width of seam lap, and quantity of dust in the seam.

The lined print cloth bag in Figure 21 has all the disadvantages of the lined jean-cloth bag and to a greater degree. Consequently it has been abandoned despite its lower cost.

The heat sealed plastic coated fabric bag in Figure 22 solved the dusting problem reasonably well for small packages of desiccant (4 ounces or lower) but did not have adequate strength for larger packages.

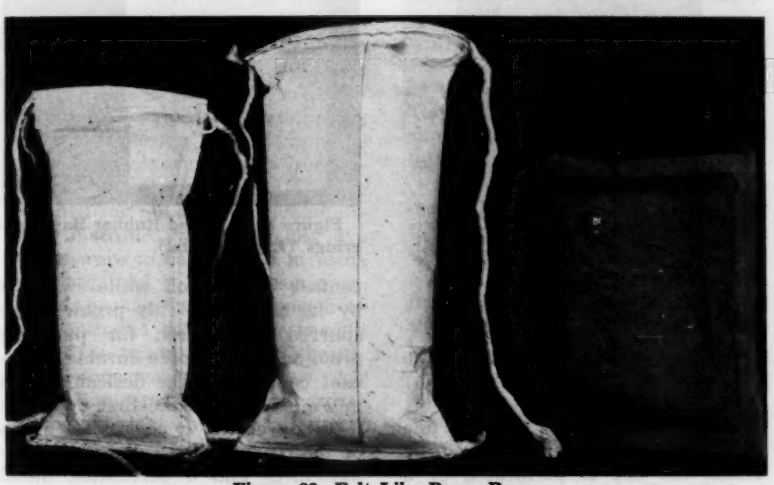


Figure 23. Felt-Like Paper Bags.

Figure 24. Punctured Cloth Desiccant Bag.

Figure 25. Desican Desiccant Container.

Studies sponsored jointly by Bureau of Ordnance and the Bureau of Ships at the end of World War II, yielded a number of paper-like desiccant bags with improved properties. Acceptable types eventually were developed with all heat-sealed seams, all sewn seams, and combinations of sewn and heat-sealed seams. Figures 23 shows examples of such packages. The felt-like paper from which most of these are made is tough and pliable even when

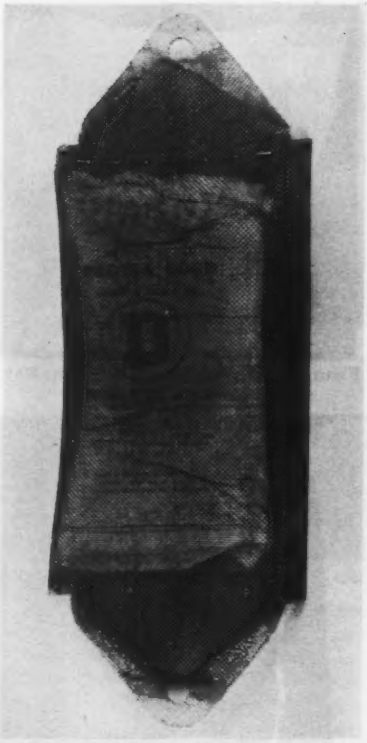


Figure 26. Screen Wire Bag Sheath (Experimental).

thoroughly desiccated and its fine weave prevents desiccant sifting unless the bag is perforated or a seam opens. The material definitely is better in quality than the liner of the jean-cloth or print-cloth bag. Unfortunately it is subject to the same shortcomings of faulty seams and skipped stitches and is somewhat more easily torn than the cloth bag.

All of the desiccant bags, particularly those with tie-strings are liable to tearing, puncturing, or bursting when in contact with sharp protrusions of the packaged item. Figure 24 shows a bag punctured by

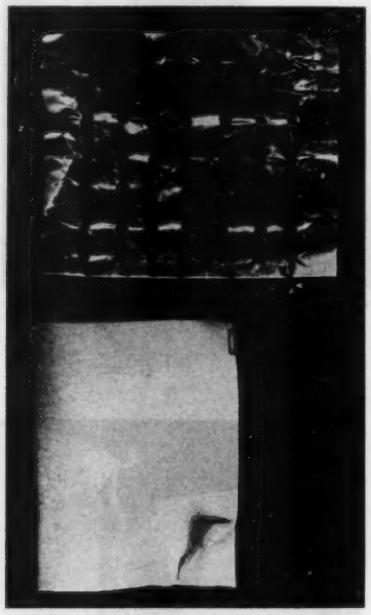


Figure 27. Foil and Rubber Bag Coverings (Experimental).

contact with a bolt while swinging by its tie-string. This problem has spurred the search for puncture proof or at least more durable desiccant containers. The desican shown in Figure 25 was the first approach to this problem. It consists of a can of desiccant sealed with a blotter-like filter and a perforated metal disc. Originally this perforated disc (or screen) is sealed with a moisture proof barrier. This is removed prior to use to permit atmospheric moisture to reach the desiccant. While this container is virtually indestructible in normal use, it is plagued to some extent with the same insurmountable problem of providing a moisture permeable cover which is absolutely dust tight. Other problems of the desican are relatively high cost per unit of adsorbent and relatively small adsorption area per

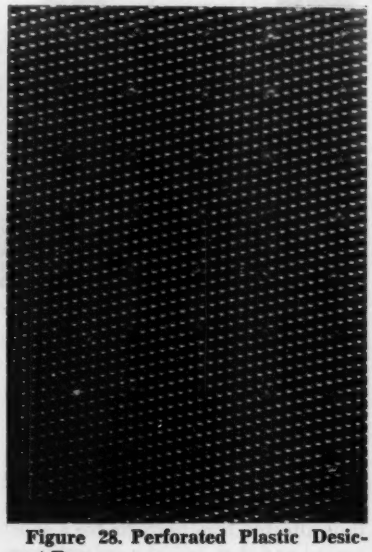


Figure 28. Perforated Plastic Desiccant Bag.

volume of desiccant.

Figures 26 and 27 show recent experimental approaches to the puncture-proof bag problem. The first is a metal screen covering for a conventional cloth or paper bag and is aimed simply at providing puncture protection. Items (a) and (b) of Figure 27 are perforated foil and thin sponge rubber sheaths which will protect against limited abuse at considerably lower cost than that of screen. These also are intended as wrappers for conventional desiccant bags.

Attempts also have been made to provide a desiccant bag which in itself is dust free, moisture permeable, and puncture resistant. The photograph in Figure 28 is a magnified view of a plastic-impregnated woven fabric perforated with microscopic holes produced by a spark gap. Theoretically the holes will transmit moisture, but not dust. Unfortunately the moisture vapor transmission rate is not high enough.

EVOLUTION OF DESICCANT SPECIFICATIONS

As with many products, formal purchase specifications for desiccant materials lagged far behind their acceptance in industry and government. Early desiccants were bought primarily on the basis of chemical analysis. Until the late thirties, very little attempt was made to define desiccant quality in terms of its expected performance.

During the period 1937 to 1939 the Bureau of Engineering and the Engineering Experiment Station began to think in terms of desiccant specifications in connection with dehydration work on refrigerating systems. Comparison of a variety of chemical and physical type desiccants for this use showed the need for a means of rating performance and controlling quality of materials obtained on contract. Already the Davison Chemical

Desiccant Limits 1940 Davison Specifications

Property	Limit (three grades) X-1	X-2	X-3
Water content, % max.	5.5	5.0	5.5
Water Vapor Adsorption, %			
At 20% Relative Humidity	10	10	10
At 40% Relative Humidity	21.75	21.75	21.75
Chemical Composition, % SiO_2	99.6	99.6	99.6
Unit Weight, lb./cu. ft.	40–55	40–55	40–55
Sieve Size, U.S. Sieve Mesh	6–18	14–20	On 42

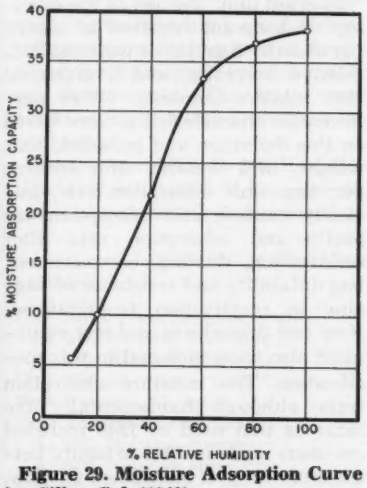


Figure 29. Moisture Adsorption Curve for Silica Gel (1940).

Company, while seeking markets for its relatively new desiccant, silica gel, proposed what proved to be an ancestor of Government specifications for desiccant materials. This specification formerly drawn up in June 1940 covered three grades of silica gel (X-1, X-2, X-3) representing large, medium and small granule sizes, respectively. The specification included requirements for water content, water vapor adsorption capacity, chemical composition, unit weight, screen and partial strength. The table below shows pertinent values recommended for the three grades.

Figure 29 shows the moisture vapor absorption curve which was applicable to all three grades and the adsorption train proposed for testing desiccant performance is shown in Figure 30.

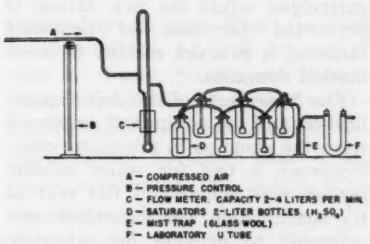


Figure 30. Moisture Adsorption Train 1940 Desiccant Specification.

The first Bureau of Ships specification for silica gel desiccant 51S32 INT of 1 November 1940, was patterned after the original Davison specification. This specified Grades A to G inclusive, where the first three were identical with the three Davison grades. Grades D to G, inclusive, represented the same materials or mixtures thereof impregnated with cobalt nitrate, a humidity indicator. Grades A and B were intended for bulk use in dehumidifying machines while the last five grades were to be supplied in jean-cloth bags of 1 to 16 ounces capacities for package uses. The specification continued the particle strength test of the original Davison specification, however, no mention was made of paper inner liners for preventing dusting. The adsorption rate curve and test equipment were identical with those of the Davison specification. A color strip card was included to assist the user in determining extent of degeneration by comparing it with the color of indicating gel. The particle sizes for the various grades were changed somewhat over the original specification as shown in the following table:

First Buships Specification (51S32 1 Nov. 1940)

Property	Limit (7 grades) A	B	C	D	E	F	G
Water Content, %	5.5	5.0	5.5	5.75	5.75	5.75	5.75
Water Vapor Adsorption, %							
At 20% Relative Humidity			8.3 for all grades				
At 40% Relative Humidity			18.3 for all grades				
Chemical Composition, % SiO_2			99.6 for all grades				
Unit Weight, lb./cu. ft.			40 to 45 for all grades				
Sieve Size, U.S. Sieves	6–16	14–20	On 42	6–16	On 42	On 42	On 42
Color Impregnated	No	No	No	Yes	Yes	Yes	Yes

Army Specification 1942 (AXF 778)

Property	Limit (3 Types & 3 Grades) Type III Grade A	Type IV Grade A	Grade A	Type V Grade B	Grade C
Water Content, % Max.	6.00	5.75	—	—	—
Water Vapor Adsorption, %					
At 20% Relative Humidity	10.5	8.6	10.5	10.0	5.0
At 40% Relative Humidity	22.0	18.2	22.0	16.0	9.0
Unit Weight, lb./cu. ft., min.			40 all grades		
Sieve Size, U.S. Sieve	6–16	6–16	On 80	On 80	On 80
Color Impregnated	no	yes	no	no	no

The Army's first comprehensive specification for desiccant materials (AXF 778, Dehydrated Agent, Activated) of 15 August 1942 went a step or two further than the Navy Department specification described above. It included three types of desiccant material based on size and color indicator impregnation and three grades based on adsorption capacity. The types corresponded to the medium and ungraded particle sizes of the Navy specification. Grade A to C represented high absorption capacity, medium absorption capacity and low absorption capacity, respectively. The Grade A material undoubtedly was silica gel while the B and C in all probability were natural clay and either activated alumina or activated Bauxite. The table at the bottom of this page shows the pertinent specification requirements for these desiccants.

The testing procedure, test equipment and general requirements of the Army specification were about the same as those of earlier specifications. However, the Army version included a contact corrosion test for the first time. This exposed sand-blasted steel specimens to the desiccant in atmospheres of 10%, 20%, 40% and 60% relative humidities. The specification also required paper-lined jean cloth bags or fiberous web serum laminated cotton cloth bags for packing Type 5 (ungraded) material. This was the first serious effort to control dusting of packaged desiccants. Requirements for package marking and qualification testing also were better in this case than in previous specifications.

About 1944 the Government forces began to coordinate efforts to prepare a unified specification. One of the first fruits of this effort was Army-Navy Aeronautical Specification AN-D-6A of April 1944 for "Dehydrating Agent (Activated)." Except for minor changes this was identical with the Army's 1942 specification (AXF 778). One interesting addition was the somewhat ambiguous general requirement that the desiccant bags be "inspected for sifting of dehydrating agent by any suitable method." This was a further attempt to test for dusting and to promote better bags.

Government coordination matured with a committee meeting in November 1944 where it was decided to adopt a common specification for the services following the general style of Specification AXF 778. As a re-

sult of this conference, the Engineering Experiment Station was requested in January 1945 to prepare a revision of BUSHIPS Specification 51S32 to include materials other than silica gel and to incorporate the desirable features of earlier specifications. The first Joint Army-Navy specification (JAN-D-169, Desiccant Activated) was proposed in March 1945 as a result of this request. Its types and grades of desiccants were the same as those of the original Army specification, except that a Type 2 (smaller particle size) and a Grade D (lower absorption capacity) were added. The small particle size (Type 2) material was intended primarily for refrigerator drying cartridges, while the new Grade D permitted purchase of activated Bauxite, a product needed to meet market demands.

The basic tests of the Joint specification and the equipment employed were the same as in preceding ones. However, a test for water soluble matter was added and the text of the specification was expanded considerably to provide for alternate sampling and inspection requirements for the several services as well as normal, protective and qualification sampling plans. The table below shows the pertinent requirements for the several types and grades of desiccants covered by this specification:

First Joint Service Specification (Jan-D-169—1945)

Property	Type II Grade A	Type IV Grade A	Type III & V Grade A	Type III & V Grade B	Type III & V Grade C	Type III Grade D
Water content, % max. ..	1.00	5.75	6.00	—	—	—
Water Soluble, % max. ..	0.30	—	0.03	0.03	0.03	—
pH of Soluble, max.	8.0	—	8.0	8.0	8.0	
Water Vapor Adsorption, %						
At 10% relative humidity	5.7	4.3	5.7	5.7	3.5	3.3
At 20% relative humidity	10.5	8.6	10.5	10.0	5.0	5.0
Unit Weight, lb./cu. ft.	37 min.	37 min.	III — 40 to 45 V — 37 minimum			52–57
Particle Size, U.S. Sieve	14–30	6–18	III — 6–18, V — on 80			6–18
Color Impregnation	no	yes	no	no	no	no

Joint Specification D-169 continued to serve the needs for all Government services for desiccant procurement from 1945 until 1953. During this period it was revised several times with minor changes, the most important ones being addition of two new desiccant types (0 and 1). Both of these were needed for dynamic dehumidifying machines used in "Mothballing" at the end of World War II. Type 0 was essentially 3–10 mesh material and Type 1 was 14 to 20 mesh. Type 0 was marketed as Grade A (highest capacity) but Type 1 was available in Grades A and B.

The first revolutionary change in desiccant specification since 1940 occurred in 1953 with publication of Joint Specification MIL-D-3464 (Desiccant, Activated, Bags for Packaging Use and Static Dehumidification). This deleted all reference to types, grades and chemical properties of the desiccants and based requirements entirely on performance characteristics. It was intended not only to prevent commercial disputes over relative merits of the various grades, but to measure more directly the characteristics for which the desiccants were being purchased. The specification introduced a new term "desiccant unit" defined as the quantity of desiccant required to adsorb (or absorb) 3 grams of water at 20% relative humidity, and 6 grams at 40% relative humidity. Other performance characteristics were based on this definition and included: unit weight, unit volume, unit content per bag, unit adsorption rate, humidity control, unit adsorption capacity and adsorption rate after reactivation, dusting, corrosiveness, bag durability and resistance of bagging to reactivation temperatures. New test procedures and test equipment also were included in this specification. The moisture absorption train although fundamentally the same as that used in 1940 included revisions made in 1947 to insure better uniformity of humidified air flow, better temperature control and better pressure control. The shaking table shown in Figure 31 was introduced for determining dusting and general bag strength properties. These tests consisted of placing the bags in cans bolted to the table top (dusting) or of suspending them by their tie strings on the backboard of the table (strength test) and oscillating the table for a prescribed period.

Figure 31. Desiccant Bag Shaking Table.

The new humidity control test was made by sealing known amounts of desiccant and water in an airtight box, decreasing the temperature of the enclosed atmosphere uniformly and checking the rate of humidity change periodically with a hygrometer.

The test for absorption rate (new) consisted simply of suspending a bag of desiccant in a bell jar, flowing humidified air past it and noting the quantity of moisture absorbed by the enclosed desiccant in a specified period.

Specification MIL-D-3464 also initiated the terms "dustproof bag" and "dustless desiccant package" which proved to be rather troublesome. The original requirement of 0.5 miligram or less dust per bag of desiccant could not be met by normal commercial production. However, attempts to meet it resulted in wide use of materials other than paper-lined jean cloth. The Lantuck packages mentioned earlier were the most prominent of these.

Continuous use of Specification 3464 on inspection test, periodic plant production check test and round-robin cooperative tests in commercial and government laboratories showed that aside from the original

overly optimistic limit on desiccant dusting, minor ambiguities in wording of the first draft were the only real shortcomings. The latter were corrected by editorial changes in April 1953.

Specification MIL-D-3464B of October 1944 attempted to increase the dust limits of "dustless desiccant" to reasonable figures. This specified maxima of 0.5, 2.5, and 5.0 mg. of dust for 4 unit, 8 unit, and 16 unit bags, respectively. It allowed a certain percentage of bags to exceed the above figures. Specimen limits of the latest version of this specification are shown below:

Joint Service Specification (MIL-D-3464B (1955))

Property	Limit
Unit Adsorption Capacity, grams	
At 20% Relative Humidity	3.0
At 40% Relative Humidity	6.0
Unit Weight, grams, max.	60.0
Unit Volume, ml., max.	55.0
Unit Adsorption rate, gram	
At 40% Relative Humidity	0.25
At 80% Relative Humidity	0.90
Adsorption Capacity after reactivation, % of original	90
Adsorption rate after reactivation, % of original	80
Dust, Normal Max., Mg.	
for 16 unit bag	5.0
for 8 unit bag	2.5
for 4 unit bag	0.5
Dust occasional max. (2 in 12), mg.	60 to 200
Dust occasional max. (1 in 12), mg.	over 200

The necessity of relaxing the dust requirements defeated an original specification objective of providing completely dustproof desiccant packages for ordnance use and reopened this point of investigation. In all other respects the new specification has worked well and still is the yardstick by which all desiccant is purchased for the Government.

The observant reader probably noted that Specifications 3464A and B deleted both the indicating type desiccant and the desiccant specifically intended for dynamic uses in dehumidifying machines (bulk desiccants). This was considered desirable in the interest of simplifying requirements. The deleted items were not abandoned, but were transferred to a new sister specification (JAN-D-3716). For all practical purposes this is specification JAN-D-169 with the package desiccant removed.

DIRECTION OF CURRENT RESEARCH

Current government development programs are aimed at improving desiccant materials, improving Method II packaging techniques and improving desiccant test methods and test equipment. A brief review of the progress to date will show the direction of this work.

Molecular Sieve

The most recent, and in many respects the most interesting desiccants to be tested at the Experiment Station are the molecular sieves developed by the Linde Air Products Company. These represent the fruits of industrial projects started in 1940, about the time the first formal desiccant specification was written. Molecular sieves are synthetic zeolites consisting of complex compounds of sodium (or calcium) silicon, aluminum, and oxygen. Controlled dehydration of original hydrate leaves an intricate lattice of tiny channels of remarkably uniform dimensions. The two principal types have channels about 4 angstroms and 5 angstroms in diameter. Incidentally one centimeter equals 100 million angstroms.

Because of their peculiar structures, the molecular sieves have unusual water absorption characteristics. Unlike other physical desiccants they adsorb approximately the same weight percentage of moisture regardless of the relative humidity of the atmosphere from which they adsorb it. The molecular sieve also is unusual in that it will adsorb relatively high percentages of water at temperatures up to 400° F. and it is very effective at a temperature of 212° F., the boiling point of water. No other commercial physical adsorbent is effective at this temperature. Since the "sieve" will adsorb at high temperature it obviously will not lose water when the temperature within a desiccated package is increased. For this reason, once a package is desiccated with a molecular sieve material, lag loop problem disappears almost completely.

The high adsorption capacity at low relative humidity makes the molecular sieve an excellent desiccant where extreme drying is required. It is capable of reducing the moisture content of an enclosed space to virtually zero and of maintaining an atmospheric dewpoint of about minus 100° F. until a relatively large quantity of water has been adsorbed. It is much less liable to contamination because it adsorbs moisture and other low molecular weight vapors which do not carbonize easily.

Molecular sieves generally are furnished as cylindrical pellets 1/16" to ⅛" diameter (Figure 32). It is worth mentioning that they are capable of extracting water, and many other small molecules from liquid systems as well as from gaseous atmospheres. For example, a molecular sieve will dehydrate alcohol effectively or remove water from a lubricating oil or fuel as well as carbon disulfide and hydrogen sulfide from the atmosphere. Their ability to adsorb CO_2 from submarine atmospheres now is under study.

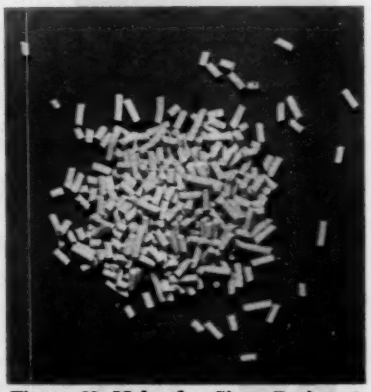


Figure 32. Molecular Sieve Desiccant.

Molecular sieve material already has been approved by the Station for use as a new type of desiccant under Specification MIL-D-3716. Time will tell if it proves economically practicable and otherwise suitable for general packaging uses.

Improvement of Packaging Techniques

An intensive study of the problems and pertinent characteristics of desiccated packages now is being made with both model packages and actual field packages in Supply Depots. Figure 33 shows a stainless steel research package instrumented for continuous humidity records at several points. It is equipped withh internals for distributing moisture, desiccant and dunnage to determine the effects of their locations on the enclosed atmosphere. Provision also has been made for inserting barriers and channels, which might affect atmospheric diffusion and therewith uniformity of humidity control.

The field packages include about 150 regular production line items at Navy Supply Depot, Mechanicsburg, Pennsylvania. These are equipped with sensing elements for relative humidity measurement and are stored in five different types of environments ranging from dehumidified warehouses to the open atmosphere. All are part of a long range program to determine average package integrity, useful desiccant life, and importance of environment.

Improvement of Tests

Present test programs are aimed at improving correlation of laboratory data and actual service results and improving agreement among testing laboratories. Effort is being concentrated on the dust test both because it is important and because it is subject to considerable variation. Cans of bagged desiccant have been shipped round trip to various cities of the United States to determine if the dust produced in handling resembles that produced on the shaking table prescribed by current specifications. Elaborate sampling and testing schedules have been prepared in cooperation with manufacturers to determine if handling and shipping of inspection samples result in significant variation of dusting values. Some round-robin tests have been conducted (suppliers and testers) and new ones are being planned to determine what order of reproducibility can be expected in the various desiccant tests.

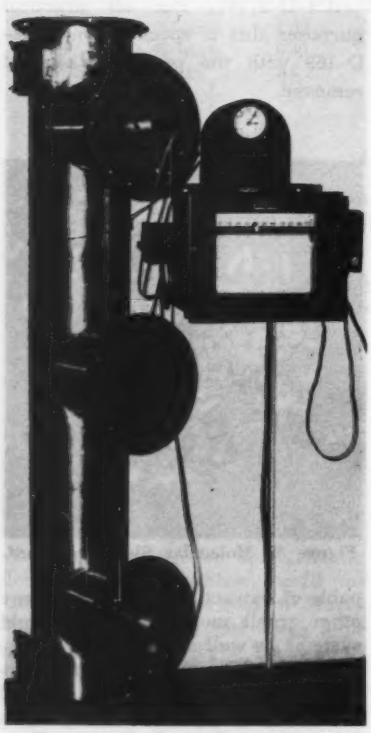


Figure 33. EES Test Package.

IDEAL DESICCANT STILL A DREAM

The development technologist is paid for reaching beyond his grasp. In the field of desiccation, as in the many other scientific fields, he must look optimistically at the future. Despite the progress already made the science of dehumidification still has a long way to go.

The ideal packaging desiccant material would be one with extremely high moisture adsorption capacity and moisture adsorption rate at the maximum safe package humidity and little adsorption capacity below that point. For the Method II package this is estimated at 30% RH. Preferably, it should be non-friable, dustless material suitable for fabrication into sheets, blocks, or other forms which would not require bags or other intimate containers. A consistency like that of sponge rubber would be ideal. The super desiccant should be regenerable but only at temperatures above 250 or 300° F. and below that temperature should lose absolutely no water to its environment. If such a desiccant could be discovered, it would be possible to maintain a package at the ideal humidity of 30% RH for extremely long periods without fear of embrittling the contents because of extremely low relative humidity, rusting or rotting them because of the lag loop phenomenon, or ruining them with abrasive dust desiccant. Needless to say there would be a ready market for such material.

If the present desiccant materials are the best we can expect for a long time to come, it may be possible to improve the situation with better desiccant containers. All one needs in this respect is a tough, readily sealable material which is extremely permeable to moisture vapor but completely impervious to everything else, particularly desiccant dust.

Method II packages themselves might be improved by using non-adsorptive dunnage and crating materials so that the desiccant charge need be responsible only for control of the atmospheric moisture. Dunnage of this type already is being used to some extent.

It also would help enormously to have a foolproof inexpensive relative humidity indicator which would show continuously the condition of the enclosed atmosphere. The present Dunmore cell equipment, although capable of indicating the humidity accurately, is somewhat too expensive and far too complicated to serve this need effectively.

POPULAR MISCONCEPTIONS REGARDING DESICCATION

Even the ideal desiccant probably would not do what is expected of it by the general public. Although desiccation is a simple process the average layman misunderstands it or expects unreasonable performance from desiccant material. He would not expect a gallon of gas to run his automobile indefinitely, however, it never occurs to him that an 8-ounce bag of desiccant costing about ten cents will not keep his basement dry indefinitely, a feat requiring a dynamic dehumidifier.

Even laboratory personnel and skilled technicians who regularly handle desiccant materials are prone to use them unwisely. It is not uncommon to find a laboratory desiccator in which the desiccant has not been changed for months or years, although the container has been open to the atmosphere daily for insertion or withdrawal of samples.

Bagged desiccant for Method II packaging operation sometimes is allowed to remain exposed to the atmosphere of a packaging room for a considerable period of time before it is finally enclosed in the moisture proof barrier.

These deficiencies cannot be charged completely against unconcern and neglect. Modern advertising techniques have trained the average human being to expect magic performance from virtually everything he uses. For the person interested in learning the proper use of desiccants, it is sufficient to say that a drying agent, like a sponge, has a finite capacity for doing its expected job. Beyond this saturation point it is as useless as a non-adsorptive material.

CONCLUSIONS

The progress in preservation by dehumidification outlined in this article show that Mark Twain was not altogether correct when he concluded that man does nothing about the weather. Supply problems during the last war certainly taught the importance of controlling the weather around vital military supplies. Thanks to the advancement in this field, many implements of defense presently are resting safely in dehumidified packages of supply depots all over the world. Let us hope that they need not be broken out for many years to come.

A simple hand computer of the circular slide-rule type, for calculating the water content of gases has been developed at the National Bureau of Standards. It has been used to calculate the water content of aviator's oxygen, rocket fuels, and fire-extinguisher gases, and can be used in such industrial applications as the determination of refrigerating system characteristics and control of moisture in inert and reducing gases.

The computer is designed primarily to calculate water content and dewpoint of gases from observations of the electrical conduction of a hygroscopic film as it absorbs water vapor. Corrections are automatically made for deviations from the ideal laws relating to vapors in gases. Such deviations are independent of measurement methods but nevertheless affect computations in which they have usually been ignored.

The computer consists of a plastic base disc about 4 in. in diameter and two smaller rotating discs marked with appropriate temperature, pressure, and altitude scales. Additional scales may be read through a plastic window in the top disc, thus extending the scope and improving the readability of the device. A logarithmic scale on the rim of the base disc resembles that of an ordinary slide-rule and may be used for a number of computations involving conversion from one unit to another.

"ENGINEERING"

THE INTERNAL-COMBUSTION ENGINE

ACKNOWLEDGEMENT

This article, written by C. St. C. Davison, Assistant Keeper of the Science Museum in London, describes some of the internal combusion engine designs that preceded the introduction of Otto's "silent" engine in 1876. It was published in the August 31, 1956, edition of "Engineering."

THE EARLIEST experiments in connection with the internal-combustion engine were carried out by J. de Haute-feuille, the Seventeenth-Century scientist. He burned gunpowder in a closed tank so that a partial vacuum was formed, thus causing water to rise into the tank. Subsequently, he burned gunpowder under a piston in a cylinder and examined the movements of the piston. C. Huyghens also carried out experiments with gunpowder. These experiments were performed a few years before Papin studied the expansion of steam under a piston, and observed that when water was heated in a cylinder, it was converted into steam, which, on expanding, lifted the piston. He then created a partial vacuum by cooling the steam so that the piston was forced down again by the pressure of the atmosphere. Although the steam engine was continually developed, the internal combustion engine remained only in the minds of far-seeing inventors who realized its possibilities. Gunpowder was obviously dangerous as a fuel.

In the Eighteenth Century, however, much was discovered concerning the nature of gases. Warltire was said to have demonstrated the explosive properties of a mixture of oxygen and hydrogen in 1781. Robert Street sought to drive an engine with the gases obtained by heating spirits of tar, or turpentine (1794). The general arrangement of the engine is shown in Fig. 1. It had a vertical cylinder (A) with an open end at the top, and a closed end at the bottom, which was located above a furnace (E). A small quantity of fuel was poured through a funnel on to the hot plate at the base of the cylinder, where it was instantly converted into gas. At the same time, the piston (B) was manually raised, by means of a lever (G), so that air was sucked in to mix with the gas. The mixture was then ignited by means of an outside flame that was held against a touch-hole (F) in the cylinder. The piston was pushed upwards and its movement was guided by the frame (D). The results obtained from this experimental engine must have shown the inventor that it was necessary to have additional engine parts: for example, to measure the

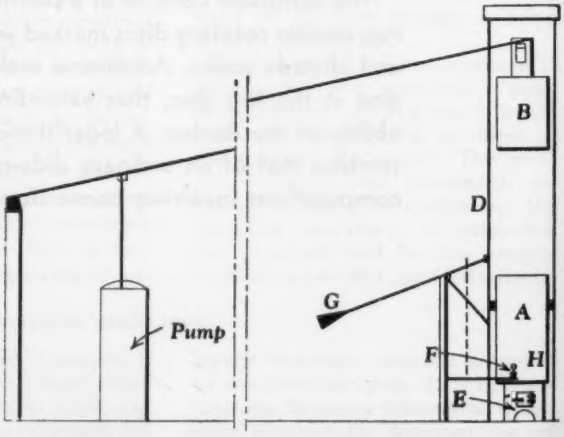


Figure 1. In 1794, Robert Street sought to drive an engine with gases obtained when spirits of tar or turpentine were heated. The gas would be ignited after mixing with air through a touch-hole (F).

correct amounts of fuel and air admitted to the cylinder, for mixing them thoroughly, and for firing the mixture at the right moment.

Phillippe Lebon patented a gas engine in 1801 which was in advance of its time. He proposed the use of coal-gas and air for driving a double-acting engine. The gas and air were to be compressed in separate pumps (L and M) driven by the main piston rod, before they were admitted to the cylinder. Then the mixture was to be ignited by an electric spark. Apparently, this was the first suggestion that the charge should be compressed before ignition but the engine, which is illustrated in Fig. 3, was never made. The manufacture and distribution of coal-gas were still in their early stages, and electricity at that time was little understood by engineers.

A proposal for a small engine that would drive various machines and at the same time serve as an alternative to the steam engine was made by Rivaz in his patent of 1807. His patent drawing, reproduced in Fig. 2, showed a single-cylinder vertical engine fitted to a road-vehicle and driven by a mixture of hydrogen and air, or other gases. Although it was a better design than Street's engine it still had only manual control for the quantities of air and gas admitted to the cylinder. The charge was fired by dropping grains of gunpowder on the heated cylinder bottom or by means of an electric spark, as proposed by Volta. The piston, which had a vertical rod connected by two pieces of chain to a pulley, was driven upwards by the explosion of the mixture. Its downstroke was the working stroke, during which a ratchet was engaged and a second pulley on the front axle of the vehicle was driven by a rope from the first pulley. The driving force was supplied by the weight of the piston and rod.

What was believed to be the first operating gas engine was a small model made by the Rev. W. Cecil who showed it working before the Cambridge Philosophical Society in 1820. It had a vertical cylinder and two horizontal cylinder-shaped reservoirs, placed end-to-end on the top of the vertical cylinder. A mixture of hydrogen and air was admitted above the piston and into the reservoirs. It was then ignited, and the partial vacuum formed above the piston and in the two reservoirs caused the piston to be pushed upwards by atmospheric pressure. A special instrument measured the amount of combustible mixture supplied to the engine. Cecil's aim in building such an engine was to overcome the drawbacks of the

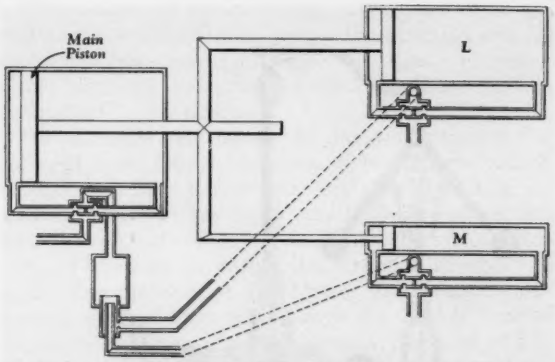


Figure 3. A double-acting engine, well in advance of its time, was patented by Phillippe Lebon in 1801. Coal-gas and air were to be compressed in separate pumps driven by the engine and the mixture ignited by an electric spark.

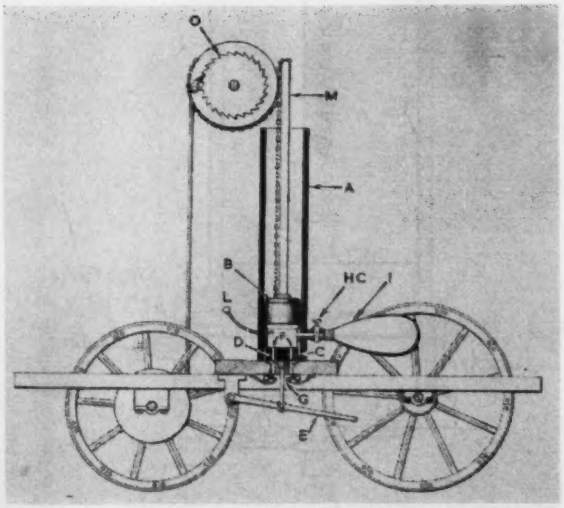


Figure 2. Hydrogen was to serve as fuel, with ignition by grains of gunpowder or an electric spark, in an engine for propelling a road vehicle proposed by Rivaz in 1807.

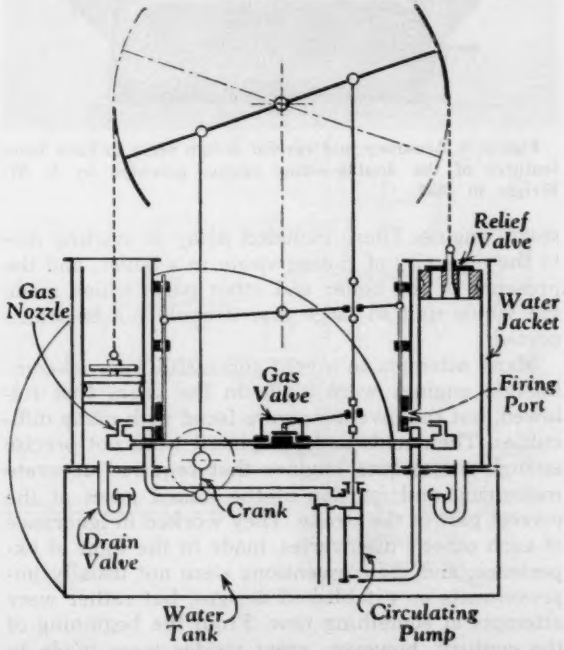


Figure 4. In most early engines the driving force was provided by the pressure of the atmosphere and the weight of the piston; the burning fuel only served to create a partial vacuum. Samuel Brown made the first full-size gas engines working on this principle early in the Nineteenth Century.

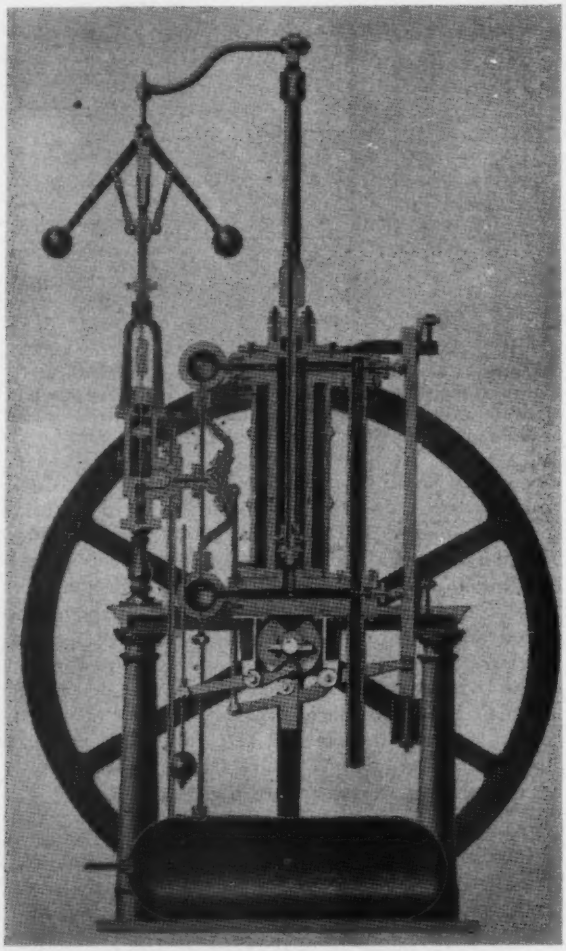


Figure 5. Accuracy and careful design seem to have been features of the double-acting engine patented by S. W. Wright in 1833.

steam engine. These included delay in starting due to the necessity of raising steam in a boiler, and the presence of the boiler and other parts which made the whole unit so large that it could not be transported.

Many attempts to invent successful internal-combustion engines were made in the years that followed, but the inventors were faced with many difficulties. Their tools and equipment were not precise enough to produce engines that required accurate measuring and ignition of the mixed gases at the correct part of the stroke. They worked in ignorance of each other's discoveries, made in the light of experience, and their inventions were not usually improvements on established designs, but rather were attempts at something new. From the beginning of the century, however, great strides were made in the development of new workshop machines and tools. The design and production of the steam engine were much improved. Inventors of internal-combustion engines naturally borrowed from steam-engine technology and some of their engines resembled contemporary steam engines.

Samuel Brown made the first full-sized gas engines that were driven by the pressure of the atmosphere acting against partial vacuums produced in the cylinders by burning a mixture of gas and air (patents of 1823 and 1826). Although his engines worked well enough they were uneconomical and much too large for the small powers produced. It was stated that they propelled a boat and a road carriage. One of these engines is shown diagrammatically in Fig. 4.

The drawings of the double-acting engine patented by S. W. Wright in 1833, one of which is illustrated in Fig. 5, gave the impression that gas engines had reached a stage of careful calculations and design. Hydrogen and air were delivered to both ends of the cylinder by pumps driven by the engine, and the mixture was ignited when the piston was passing dead-center by flames applied to touch-holes. The spent gases were pushed out through exhaust valves near the ends of the vertical cylinder.

Probably the first engine in which the charge was compressed before ignition was made by William Barnett who described single-acting and double-act-

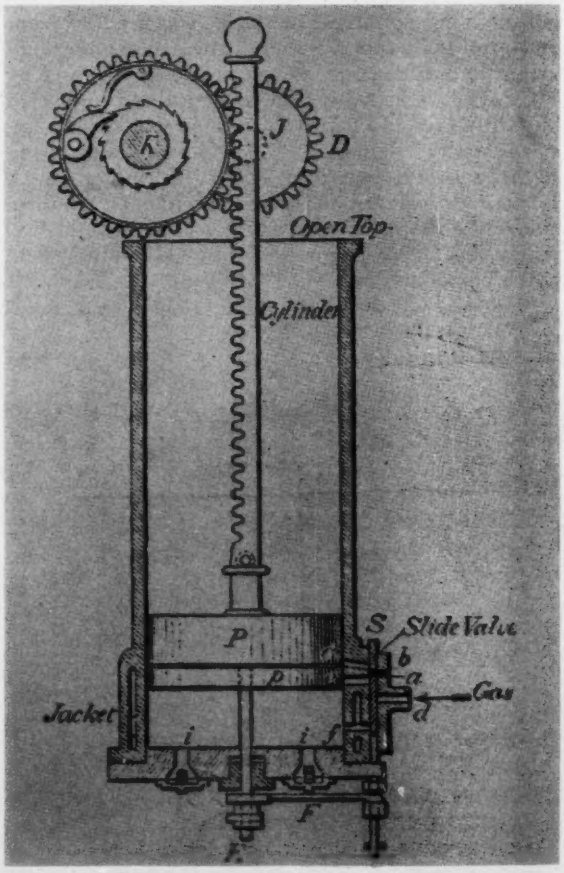


Figure 6. E. Barsanti and F. Matteucci are said to have built the first free-piston engine in 1857. The piston was free on its upward stroke.

ing compression engines in his patent of 1838 and thus led the way to the modern internal-combustion engine. Two pumps, driven at twice the speed of the main crankshaft, separately compressed the air and the gas, which were then mixed in the main cylinder. Since the mixture was compressed, ignition through the usual touch-holes had to be abandoned and he invented a special flame-ignition cock which was used for many years.

E. Barsanti and F. Matteucci patented an early free-piston engine (1857). Although it was the first of its type this engine had certain features common to earlier engines. As can be seen from Fig. 6, it had a long vertical cylinder in which a charge of gas and air under the piston was electrically ignited; and it had a piston that was entirely free on the upward stroke. On its down-stroke a rack on the piston-rod engaged with a toothed wheel and provided driving-power arising from the combined weight of the piston and atmospheric pressure. This type of engine, in an improved form, was later re-invented by Otto and Langen.

When J. J. E. Lenoir built his gas engine (patented in 1860), a very definite stage in the development of internal-combustion engines was reached. Shown in Fig. 7, it embodied many principles already well known, and the design incorporated much of steam-engine practice. Tools, machinery, and materials had reached a stage when engines could be made more cheaply and efficiently. The consequence was that Lenoir's engine, which was of horizontal double-acting design, was the first internal-combustion to work with reliability.

Slide-valves of steam-engine pattern admitted air and gas into the cylinder where the mixture was ignited at atmospheric pressure by means of spark plugs, Bunsen batteries, contact breakers and a Ruhmkorff induction coil.

But although the Lenoir engine was successful it suffered from delayed ignition of the charge, which caused the piston to move at very slow speeds. It required too much gas for a small power-output and thus proved expensive to run. It had the effect, however, of showing inventors the direction in which to apply their talents in developing the internal-combustion engine. How to improve the Lenoir type of engine became the main problem. G. Schmidt and F. Million each separately proposed that compression of the charge before ignition would be very beneficial for efficient combustion of the fuel (1861).

In 1862 Beau de Rochas patented a cycle of operations for gas engines and thus probably made the most important contribution to the evolution of the internal-combustion engine. The majority of modern engines work on this cycle. Among other things, he stated that (1) the gases were to be drawn in during one whole stroke of the piston; (2) the mixture was to be compressed during the following stroke; (3) the mixture was to be ignited at the end of the compression stroke; followed by the expansion of the burning gases during the third stroke; and (4) the burnt gases were to be discharged during the fourth and last stroke of the cycle.

Beau de Rochas only enunciated this brilliant theory and never built an engine to give it practical confirmation. But engine builders continued improv-

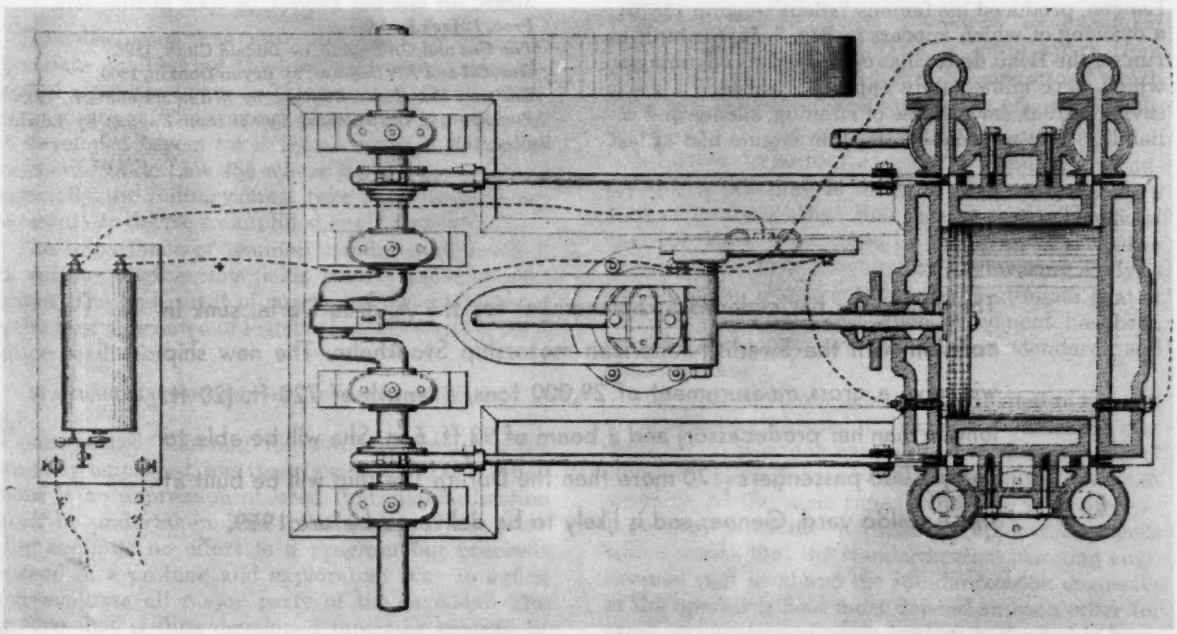


Figure 7. Slide-valves of steam-engine pattern and spark plugs were features of a gas engine patented in 1860 by J. J. E. Lenoir. Of horizontal double-acting design, it is thought to be the first internal combustion engine to work with reliability. Delayed ignition, however, caused the piston to move too slowly.

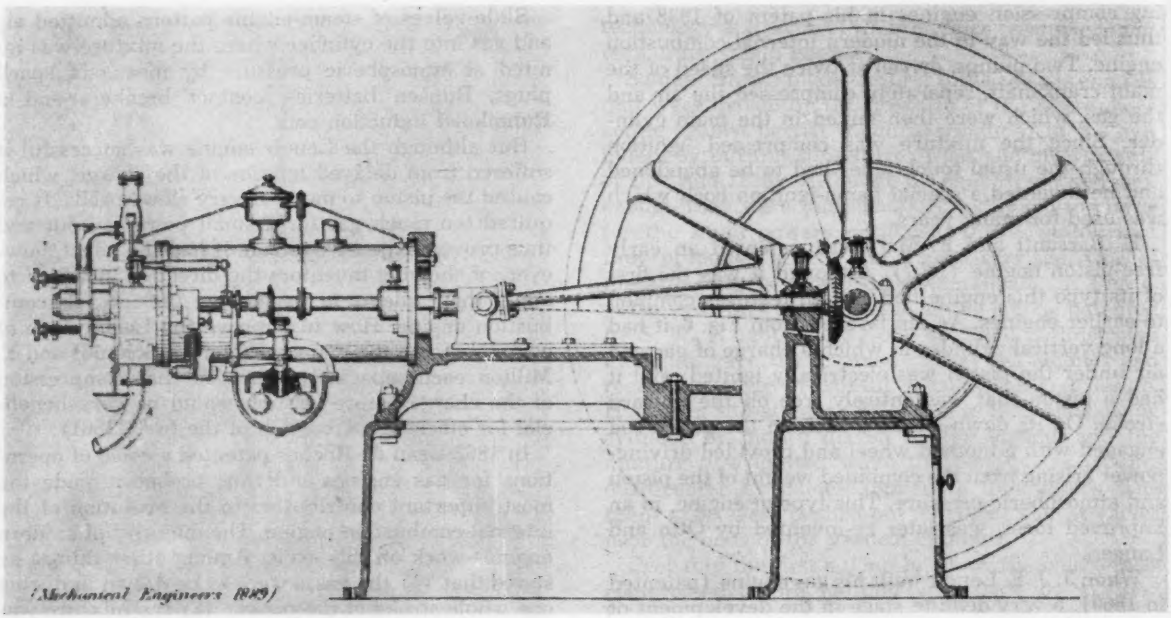


Figure 8. With Otto's "silent" engine, built in 1876 to run on the Beau de Rochas cycle, the internal-combustion engine entered its modern stage of development. It was smooth running, reliable and economical in fuel, and was suitable for use in workshops where space was limited.

ing their engines on the lines of the old principles for some years, and it began to appear that unless something better was produced, the internal-combustion engine would have to leave the field clear for the steam engine. It was then that Otto, who had been making a noisy and slow free-piston engine with Langen, produced his famous "silent" engine (1876), a drawing of which appears in Fig. 8. It was built to run on the Beau de Rochas cycle, and its advantages, which were immediately apparent, included a great saving in fuel, smoothness of running, silence and reliability. The internal-combustion engine had at last reached a stage in which it was welcomed in small workshops where there was no room for a steam engine.

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The Italia Line has ordered a replacement for the Andrea Doria, sunk in collision with the Swedish-American motorship Stockholm. The new ship will have a gross measurement of 29,000 tons, a length of 720 ft. (20 ft. longer than her predecessor) and a beam of 93 ft. 6 in. She will be able to carry 2,000 passengers (170 more than the Doria). The ship will be built at the Ansaldo yard, Genoa, and is likely to be delivered before 1959.

ELLSWORTH F. SEAMAN

STANDARDIZATION AND ENGINEERING PLANNING

THE AUTHOR

Articles by Mr. Seaman have appeared in the ASNE Journal over a period of years, starting with the November 1934 issue. The present article reflects some portion of the author's standardization experience that had its beginning in 1931 in the Bureau of Engineering.

Mr. Seaman is a Registered Professional Engineer, Head of the Standardization and Conservation Planning Branch of the Bureau of Ships, Chairman of two committees and one sub-committee in the International Electrotechnical Commission and one of the four United States members of a task group concerned with Pan American standardization.

PREFACE

This discussion has been prepared in order to stimulate engineering thinking and planning as essential elements in the achievement of standardization objectives. The concept of engineering planning as developed herein takes into account the requirements of Public Law 436 where the government and especially the military must take such steps as are necessary to devise a simplified supply system.

The importance of planned standardization effort in various engineering fields cannot be over estimated. The end result of successful accomplishment is the best guarantee of logistical support and mobilization readiness.

STANDARDIZATION AND ENGINEERING PLANNING

Engineering planning for standardization, when properly employed, has its origin at that point when there is an expression of need that standardization work be undertaken. The initial phase of the planning commits no effort to a program but proceeds instead in a probing and exploratory way to define and evaluate all major parts of the problem. The picture that is thus developed indicates priority of the problem parts, potential benefits, most economical methods of approach or, in some cases, may result in nonactivation of a project because of questionable beneficial returns when compared to expended effort. Planning of this type is quite apart from scheduling and progress-following operations which represent the administrative support effort normally carried out by non-engineering personnel.

A further important concept in discussing standardization planning is to think of it in terms of a kind of catalytic effort that should start a beneficial chain of reaction governed by the terms of reference of the master plan provided by engineering analysis and thinking. Documentation is the ultimate goal of much of the effort and when agreement has been reached the results are published in standards and specifications.

The value of planning is directly related to breadth of engineering viewpoint; hence it is indicated that engineering planning can best serve the purposes of standardization by operating in a centralized staff capacity. At the same time, it must be very directly associated with the realities of application needs which means that the standardization planning engineers at staff level and the standardization engineers in the operating field must depend on each other for cross fertilization of ideas leading to workable long-range plans of action. The standards engineers at project level are the ones who will achieve agreements with their counterparts in order to develop the

standards documents. The scope of such documents and the need for them is generally defined as the result of engineering planning.

Areas of standardization effort are, in a great many cases, interpreted as consisting only of items of supply. There are, however, other across the board types of interest that require as much or more planning and coordination than would be the case for hardware or consumer items. Examples of this include: drawing room practice, terminology and environmental test standardization. Absence of adequate planning in these and similar areas can reduce specification usefulness covering many end items and can lead to unjustifiably expensive investments in laboratory facilities. Importance of environmental test work is increasing at a rapid rate on a national scale and is closely related to current international programs.

Planning actually begins when the problem is viewed in perspective and this picture develops out of a definition of all of the pertinent considerations. The standardization of electric motors may be used as an example to illustrate many of the basic factors that are always considered during the initial planning phase. The avenues of approach that are explored for this specific problem should be considered as generally applicable to a variety of end items involving mass production and mass usage. Products such as fasteners, valves, bearings, and gasket or packing materials fall into this category. An analysis of the specific motor problem includes the following:

Initial Planning Conference

The initial standardization planning conference should form the basis for definition of all basic considerations. All personnel having responsibility and interest in this area of standardization should be represented in this conference.

Supply Classification

Each motor type should be identified with a supply classification number. This provides a mechanism for later simplification action. The Federal Supply Classification for electric motors is 6105. It includes, in addition to motors, such spare parts as armatures and field windings. These spares are proprietary to specific motor designs and are automatically reduced or eliminated during the simplification of the supply system for motors.

Background

A certain amount of background, forming the basis for existing standards and specifications is essential to an understanding of the current standardization problem. As a part of this background, it is useful to point out those areas which have received major attention in the past because of their importance in the work of the application engineers. In the case of motors, a statement concerning the relative importance of fractional vs. integral horsepowers is of value.

An understanding of the basis of rating for motors is important since this determines motor size and simplification trends. Generally speaking, motor ratings in industry are based on insulation temperature limits depending on the type of insulation used. Ambient temperatures used with permissible temperature rise will control selection of frame sizes.

Interchangeability

Interchangeability is a primary objective of standardization. In motors it means establishment of maximum permissible overall dimensions and mounting dimensions; definition of functional requirements such as horsepower, speed, and voltage; and a statement of performance quality as measured by standard test methods.

Documentation

If there is any question about where to use design type specifications or performance specifications, the decision should be reached at this point. As a general rule, a consumer needs performance specifications.

A general scheme should also be developed as to breakdown in coverage for each document needed to make up total coverage for the field. It might be decided that a total of four documents would be needed, namely: integral horsepower DC, integral horsepower AC, fractional horsepower DC, and fractional horsepower AC.

Obsolescence

Adequate planning should lead either to the elimination, or reduction to a minimum, of item obsolescence which may result from standardization effort that results in a simplified system of supply. As an example, it might be found possible to eliminate fifty per cent of the variations in motor sizes, types, etc. It is essential that conversion from past to new supply practice be controlled by instructions to using activities so as not to freeze existing stocks as non-issuable. Provision must be made for issuance until exhaustion of current stocks.

The effect of research and development on simplified supply decisions must also be considered as a possible obsoleting influence. The development of motors using silicone insulation permits higher temperatures and the use, for a given horsepower rating, of a smaller frame size motor than presently in the supply system.

Financial Support

It is essential that a long-range view be taken concerning standardization objectives over a period of years. Since financial support is sometimes essential to the achievement of standardization goals, it is important to project planning into the future to assure adequate appropriations in support of this work.

International Work

It is never too early to evaluate international relationships in standardization work. It is, in fact, much easier to give and take in international bargaining before national interests have been committed to unchangeable producer and consumer standards. The least that should be done on the subject of motors should be a continuing type of liaison with international industry through the International Electro-

technical Commission and their Technical Committee No. 2 for Rotating Machinery.

Societies and Associations

Appropriate societies and associations represent important liaison points where standardization work is sponsored and carried out. It is important, therefore, to utilize the results of such group effort wherever it applies to the problem at hand or where such bodies may contribute to the achievement of standardization goals. In the field of electric motors, such bodies as the American Institute of Electrical Engineers and the National Electric Manufacturers Association should not be overlooked. The over-all point for liaison between industry and the Government is found in the American Standards Association where certain projects are currently active which will have an influence on motor standardization. This includes terminology in the new dictionary of electrical terms which is now a proposed publication. Through a revision of AIEE Standard No. 1, there are important test methods and temperature classifications which will be a U.S. national guide as well as being compatible with proposed international standards.

Terminology

It is necessary to establish liaison with those activities engaged in terminology work. This involves the definitions for motor enclosures where the subject is significant to other fields as well. Simplification in enclosure terminology can directly effect reductions in motor types.

Preferred Number Application

Special emphasis should be directed toward the selection of a full coverage of sizes with the maximum economy in selected standard units. The most important single guideline in this connection is the use of preferred numbers.*

Long-Range Plan

Consideration should be given to the approach which would be taken in the preparation of a long-range plan for simplification and other types of action. The aspect of simplification, since it is one of the major standardization efforts, would require a rather thorough analysis of the whole range of supply for motors so that on a theoretical basis, an adequate number of standard items might be designated and from this a super selection of preferred items might be specified. This long-range plan would represent the ideal situation if all manufactured frame sizes were consistent and if the user could proceed without inhibitions concerning past practices on best use of different items.

Short-Range Plans

The short-range engineering plan would select from the long-range plan those areas having the highest priority and representative of the kind of effort where the greatest savings might be immediately realized. It must also take into consideration those points at which it is feasible to take more immediate action than would be the case with some of the evolutionary longer time portions of the long-range plan. The short-range plan would represent the smaller and most manageable portions of the total work.

Basic Test Methods

Measurement of standard performance by standard test methods is an important part of any standardization program. It is therefore important to relate this work to existing standards in the broad field of environmental tests where the best guidelines are available.

Associated Components

In the field of motor standardization, it must be recognized that there are individual components which go into the motor and which fall within other fields of standardization. This includes such items as bearings, magnet wire, lubricants and fasteners. Liaison must be maintained with these associated fields to insure full use of standardization efforts having "across the board" significance.

Data Tabulation and Analyses

In attempting to analyze the importance of the similarities and differences when many items of supply exist, it is essential that the most economical approach to this be used. Manual listing techniques can be time consuming and wasteful. In the case of electric motors, the amount of work and detail involved would recommend the EAM (Electric Accounting Machine) or punch card approach.

Reporting

Continued work on any major standardization project depends on making available to management such information as will tie together the use of appropriated funds, the cost of the standardization work and the monetary as well as other economies resulting from the completion of this work or some phase of it. Reporting is therefore to be considered an essential part of the standardization program.

* * *

Engineering planning enters into all phases of a standardization program where it is important to a full understanding of the trends which are developing within the program. There are several specific points which are most important to engineering thinking and its potential influence on the direction of the work. These points fall under Parts I, III, IV and VII in the following outline:

I. General Planning Conference

This is the initial conference which would normally take place before any standardization work is done. Its purpose is to define all the basic considerations that pertain to the problem and to explore all avenues of approach so that the work can most effectively be carried out. An operation of this kind is fully discussed above.

II. Collection of all Pertinent Data

This operation would be performed by engineering aides or administrative personnel. It includes the col-

* American Standard Preferred Numbers Z17.1 or Bureau of Ships Standardization Manual, Chapter 2.

lection of use data, supply information, existing specification documents, and such other material useful to the program.

III. Data Analyses

Data analyses includes the tabulation of data and its arrangement in such a fashion that all of the significant information may be made available with a minimum of work. The selection of characteristics under which the information is classified is an important phase of the planning work. Similarities and differences are necessary factors which should show up readily as a result of the way in which the data are listed.

The analysis of each part of the data is a function of the technical project engineer charged with the responsibility for this part of the program.

IV. Engineering Planning Evaluation

The analyses have the objective of determining how a simplified supply system may be best developed. This is a joint effort between the standardization engineers in the planning and operating portions of the activity. In addition to simplification, it may be indicated that testing programs should be set up or that unsatisfied needs exist and should be covered.

V. Scheduling

The scheduling of work as to priority of the different phases and areas in which projects will be undertaken, is a function of engineering planning decisions that have been reached up to this point. The scheduling and project progress reporting work is carried out by administrative personnel. The assignment of projects is the result of mutual agreement between interested participants in the total standardization program.

VI. Standardization Decisions and Documentation

Standardization decisions are made by personnel having responsibility for applications but on the basis of thorough consideration of those recommendations that develop out of engineering planning. These decisions control the type and kind of documentation that must be prepared. They include the elimination of needless variety and the adoption of a simplified supply system framework.

VII. Final Evaluation

This includes a complete report of the standardization cycle concerning use of money, cost of doing work, and the savings that result from standardization accomplishment. This is an important aspect of engineering planning and provides well-grounded justification for appropriations for future work. Standardization planning depends on standards engineers in the application field to provide accurate information as to actual accomplishments which have been achieved.

VIII. Maintenance of Standards

A continual amendment or revision program for specifications and standards must be maintained. This will keep the standardization agreements current and insure the highest validity and use for each published agreement. This is a continuing task of the standards engineer.

Maintenance of standards requires also a continual educational program between producers and consumers so that commonly available standard parts are used wherever practical. If this is not done, special parts will be found in many equipments when standard parts would have served the purpose far more effectively. A monitoring program may be required to insure best use of available standards.

Engineering planning for standardization must necessarily assume the responsibility of finding and recommending mechanisms to facilitate the accomplishment of objectives. These actions range from recommendations for new or revised policies that control the course of standardization, to improved techniques for handling complex problems. An example of this latter aspect consists of the analysis of thousands of records of supply of electric motors. This problem involves description and listing of essential characteristics of each motor for the purpose of simplification studies.

AN EAM (ELECTRIC ACCOUNTING MACHINE) TECHNIQUE

The punched card automatic machine approach was indicated as a time saving device. A pattern study was therefore initiated with the purpose of fully exploring the potential benefits of this technique for more extensive application. Guidance rules for the study were devised along the following lines:

a. Only those characteristics that could be used directly or indirectly for simplification or other standardization actions were selected for coding.

b. A significant coding system would be used insofar as this was found practical.

c. The maximum economy in coding digits was important while at the same time insuring more than adequate capacity within the code.

d. A special symbol would be used for the coding space where the information was not available, not applicable or beyond the capacity of the code.

e. An accuracy of at least 95% would be required in the coding operation.

f. A miniature film of the complete item record would be mounted on each punched card so as to provide ready access to uncoded data, if needed.

Some interesting coding techniques were developed during the motor coding operations. They are repeated here because of their provision for adequate coding capacity with greatest economy in digits. They are:

Horsepower

A = Everything below 1/100
B1 to B9 = 0.01 to 0.09 HP
C1 to C9 = 0.1 to 0.9 HP
D1 to D9 = 1 to 9 HP
10 to 99 = 10 to 99 HP
F1 to F9 = 100 to 900 HP
T = Torque

Speed

B1 = Below 100 RPM
01 = 100 RPM to 200 RPM
02 = 200 RPM to 300 RPM
etc.

Dimensions

Fractional Dimensions were expressed in 64ths thus saving two digits. As an example, the dimension 15/16 would be coded as 60 meaning 60/64.

The coded card arrangement with film is illustrated in Figure 1. A completely coded item and its explanation appears in Figure 2. A reproduction of one of the pages from the machine run is illustrated in Figure 3. This listing required the grouping of all motors according to similar mounting dimensions.

The coding operation immediately brought to light the use of more than 80 different names for motor enclosures. A potential of 75% simplification in terminology exists in this area alone. This can reflect itself in simplified stocking and issue.

The most difficult part of the punched card operation is the coding of characteristics and this problem can be greatly reduced if engineering assistance is available for the operation.

The motor punch card task was a relatively small one consisting of about 5000 cards. It is conservatively estimated that about two man years will have been saved by the machine method compared to the manual method of individual listing and arranging information in proper sequence. This takes into account the coding time required for the punch card operation.

GENERAL CONCLUSIONS

A generalized summarization of the foregoing will, it is believed, support the following conclusions:

a. The punched card technique for analyzing similarities and differences can render an indispensable service by saving manpower in those instances where a great variety and number of items exist. This applies to electrical, mechanical, electronic and other fields of engineering.

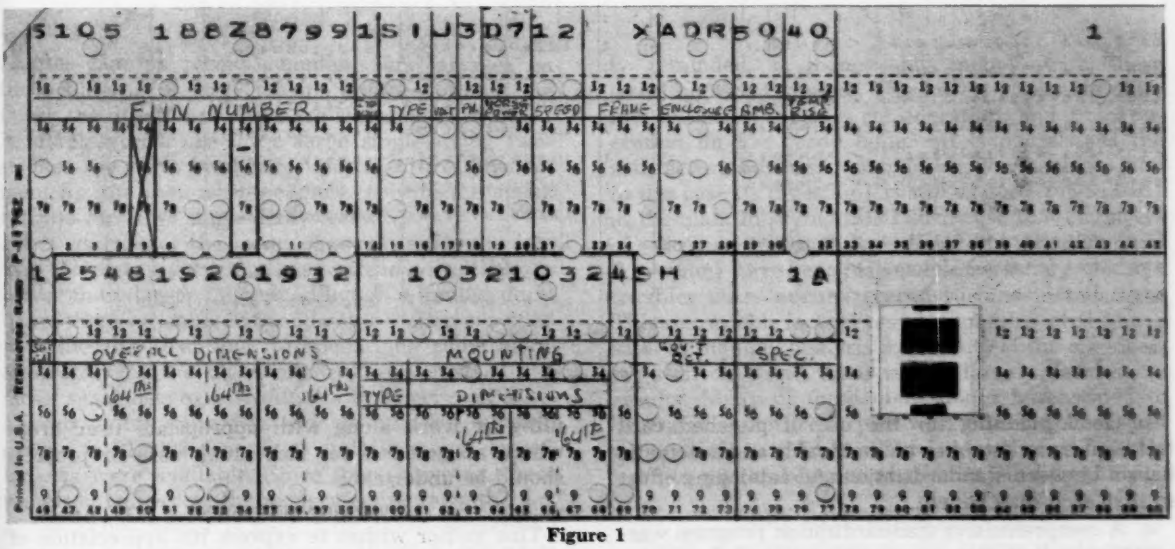


Figure 1

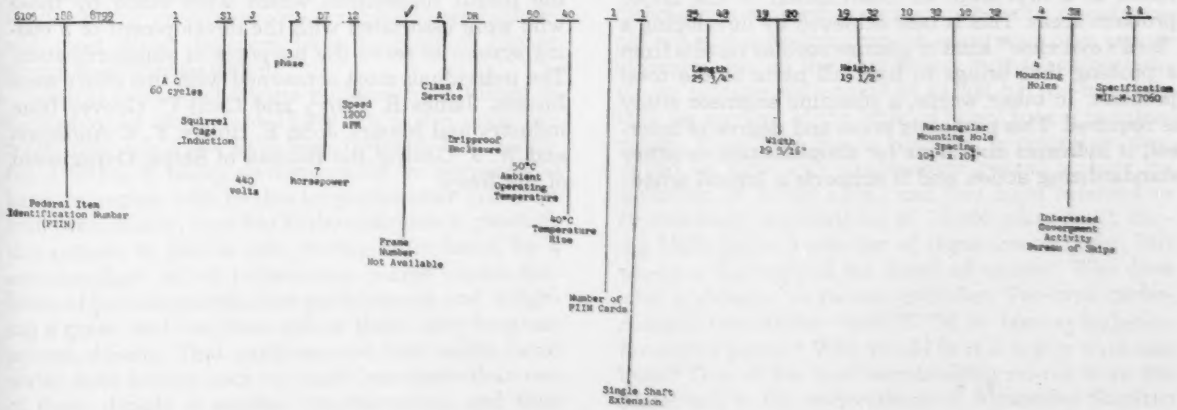


Figure 2

DEPARTMENT OF DEFENSE — STANDARDIZATION OF F S C 6105 (MOTORS)

FIIN NUMBER	ITEM NAME	TYPE	VOLTAGE	POWER	SPEED	FRAME NUMBER	ENCLOSURE	AMBIENT	TEMP. RISE	UNASSIGNED	NO. OF FIIN CARDS	SHAFT EXT.	OVERALL DIMENSIONS LENGTH IN.	LENGTH DEC.	WIDTH IN.	WIDTH DEC.	HEIGHT IN.	HEIGHT DEC.	MOUNTINGS TYPE	DIMENSIONS IN.	DIMENSIONS DEC.	DIMENSIONS IN.	DIMENSIONS DEC.	NO. HOLES	GOVT ACT.	SPECS.	REMARKS
6105 635-1238	1	S	I	J3D	8	17	✓	AEN	50	45		1	23	60	13	48	15	52		9	32	9	32	4	NMCO	1A	
6105 635-2204	1	S	I	J3E	1	35	✓	CEN	50	50		1	18	24	16	24	17	24		9	32	9	32	4	NMCO	X	
6105 635-3066	1	S	I	J3D	5	12	✓	CDR	40	55		1	18	00	16	24	17	00		9	32	9	32	4	SH	10A	
6105 635-5982	1	S	I	J3D	6	17	✓	CDR	40	50		1	18	44	16	46	17	32		9	32	9	32	4	NMCO	X	
6105 635-6123	1	S	I	J3E	1	16	✓	AWT	40	X		1	21	90	8	13	56	17	24	9	32	9	32	4	NMCO	1A	
6105 643-0237	1	S	I	J3D	5	12	✓	CDR	50	45		1	18	56	14	00	14	04		9	32	9	32	4	SH	X	
											62																	
6105 295-1546	1	S	I	J3D	8	17	✓	CDR	50	✓		1	18	44	13	62	17	60		9	32	11	00	4	NMCO	X	
6105 548-2258	1	S	I	J3E	1	35	✓	CDR	50	40		1	18	00	14	00	17	00		9	32	11	00	4	SH	10A	
											2																	
6105 548-2445	1	S	I	J3D	4	18	✓	CIT	✓	40		1	17	00	15	00	15	48		9	48	9	48	4	SH	X	
											1																	
6105 635-0790	1	S	I	J3C	5	6	✓	CCF	50	40		1	16	40	12	32	12	32		10	00	10	00	4	A	X	
6105 635-0855	1	S	I	J3E	2	35	✓	AST	50	65		1	19	08	13	62	17	00		10	00	10	00	4	NMCO	1A	
											2																	
6105 635-0235	1	S	I	J1D	2	14	✓	CEN	85	65		1	11	03	2	11	00	11	08	10	16	4	16	4	AF	X	
											1																	
6105 25-3960	1	S	I	J3E	1	35	✓	AEN	50	✓		1	22	60	15	40	20	00		10	32	10	32	4	SH	1A	
6105 188-8791	1	S	I	G3D	H	CS	✓	ADR	50	✓		1	20	16	15	16	19	16		10	32	10	32	4	SH	1A	
6105 188-8794	1	S	I	J3D	H	CS	✓	ADR	40	50		1	20	08	15	56	19	20		10	32	10	32	4	SH	1A	
6105 188-8799	1	S	I	J3D	7	12	✓	ADR	50	40		1	25	48	19	20	19	32		10	32	10	32	4	SH	1A	
6105 222-4727	1	S	I	J3E	1	18	✓	ADR	50	45		1	18	32	18	40	18	40		10	32	10	32	4	SH	1A	
6105 222-4732	1	S	I	J3E	1	18	✓	ADR	50	45		1	20	08	19	20	21	52		10	32	10	32	4	SH	1A	
6105 222-4744	1	S	I	J3D	H	CS	✓	AFO	50	45		1	22	56	19	16	19	40		10	32	10	32	4	SH	1A	
6105 222-4749	1	S	I	J3D	8	12	✓	ADR	50	45		1	19	32	18	40	18	40		10	32	10	32	4	SH	1A	
6105 222-4750	1	S	I	J3D	8	12	✓	ADR	50	45		1	20	08	19	32	21	32		10	32	10	32	4	SH	1A	
6105 222-4757	1	S	I	J3D	8	18	✓	AWT	50	45		1	20	56	18	08	20	24		10	32	10	32	4	SH	1A	

Figure 3

b. Good planning for the use of punched card techniques can establish an invaluable and automatic liaison between standardization and cataloging effort so that each may benefit.

c. A comprehensive standardization program warrants, as a first step, an examination of the major problem areas. This is best achieved by developing a "bird's eye view" kind of picture such as results from a probing that brings to light all parts of the total problem. In other words, a planning engineer study is required. This pinpoints areas and degree of interest; it indicates directions for simplification or other standardizing action and it supports a logical scheduling of work along with appropriate user areas where assignments for individual tasks or projects should be undertaken.

ACKNOWLEDGEMENT

This author wishes to express his appreciation of the useful suggestions which were made by those who were associated with the development of a coding system to serve the purposes of standardization. The individuals most concerned with this effort were Messrs. James R. Curry and Cecil C. Grover from industry and Messrs. John E. Burke, F. E. Anderson and W. J. Glod of the Bureau of Ships, Department of the Navy.

"THE MARINE ENGINEER and NAVAL ARCHITECT"

HIGH-POWERED SINGLE-SCREW MOTORSHIPS

ACKNOWLEDGEMENT

This is an article submitted by a correspondent to the editors of "The Marine Engineer and Naval Architect," and published in the October 1956 edition of that publication. The author's name was not given.

YOUR VARIOUS recent comments and articles on turbocharging of large marine engines prompt me to ask the question: Where are we going from here? In other words, are these large single-acting two-strokes the most promising line of future development for the motorship people's reply to the steam turbine for large single-screw vessels?

Let us look at the trend of events since the late war. The geared turbine was already available to power these larger tankers, although a limited number of them—notably in Scandinavia—were provided with diesels. Meantime, turbocharging came along apparently at the right moment and enabled the diesel specialists to raise outputs by 35 per cent or so. Thereby, after an understandable time lag, suitable diesels for 18,000 tons d.w., and somewhat larger, tankers were available. Since then, however, these vessels have become the moderate-size ones; the day of the 32,000-tonner is here, with 44,000-tonners by no means uncommon. Engines of 10,000/12,000 b.h.p. service rating are inadequate for these super-tankers and most diesel builders have nothing of higher power to challenge steam.

Several marine oil engine builders have talked of turbocharged engines of 15,000 b.h.p. but none are built, although a few have been ordered. It is doubtful, I think, if many owners would be prepared to have an engine with twelve large-diameter cylinders and, presumably, four big turbo-chargers to produce this output. It can be met, on the other hand, by a commonplace set of twin-casing geared steam turbines of proved trouble-free performance and weighing a great deal less than one of these very long unproven diesels. That turbines and two easily rated water-tube boilers take up much less space than one of these diesels is another consideration, and time and money for overhauling will favor steam in most cases over the life of the ship. Time, we are frequently reminded, is money—big money—with these large, high-cost tankers. The lowest attainable daily fuel bill is not the only consideration; and diesel operation on low-grade boiler oil is not always the satisfactory business it should be. The machine (and in this case its digestion) is still as good (or as bad) as the man. In saying this I am aware that engineers of various nationalities (including British and American) have been responsible for some expensive troubles with modern geared turbine installations. This regrettable fact serves to emphasize what I have said. In the final analysis the quality of the engineering staff on board these vessels largely decides the results. Many of these men should be confined to saturated steam triple jobs with Scotch boilers, just as some of the men at sea today are not sufficiently keen to get the best out of a boiler oil diesel ship.

LARGE DIRECT-COUPLED ENGINES

These reserved views on the bigger single-screw, direct-drive motorship concern what the diesel people are just now bringing out—see your own report in September on the *first* Sulzer turbocharged two-stroke commercial engine of 11,800 b.h.p.—but they take no account of the bulk of likely future requirements. Your 1954 Steam Number, I remember, described an American single-screw geared turbine installation of 22,000 s.h.p., and you have referred to British-built installations of 20,000 s.h.p. built during 1956. Quite a number of these are on order, but where is the reply of the diesel advocates? Who dare offer a sixteen- or twenty-cylinder, Vee-type turbocharged two-stroke—with 27/30 in. bore cylinders—for such a power? Who would fit it in a ship were one built? One of the most encouraging moves from the diesel side is the undertaking of Alexander Stephen & Sons Ltd. to build a twelve-cylinder, in-line turbocharged engine of the same bore and stroke (760 by

1,550 mm.) as the nine-cylinder one you recently described. This engine will be capable of developing 18,000 b.h.p., it has been stated, although the Swiss-built engine is rated at just over 1,300 b.h.p. per cylinder as against this 1958 (?) engine's 1,500 b.h.p. In passing, it is worth noting that the most widely used large British engine, the Doxford, would have to produce 3,000 b.h.p. per line to achieve this figure. A seven-cylinder engine has been proposed in papers by the Doxford designers but by all accounts nobody is very interested in the idea. It would seem that no reply is likely to be forthcoming from this group (with more than twenty licensees) to the steam turbine installation for these fairly high-powered, single-screw ships.

The situation is disturbing enough for the diesel camp up to ships of these sizes and powers. A good deal of the future would seem to lie with the 60,000 and even 85,000 tons d.w. vessel, however, judged by the trend of tanker orderings; and the Onassis Group are likely to build a 100,000-tonner in the States, we hear. Even for moderate service speeds 20,000 s.h.p. seems inadequate for the smaller of these "super super" tankers; and it is possible that the outsize Onassis vessel will have twin sets of geared turbines each of about this size. What can the diesel people offer for these? They know the answer.

PIELSTICK MULTI-ENGINES SCHEMES

The Pielstick advocates could, I admit, provide a paper proposal for any single-screw power required. How many hard-headed tanker owners, remembering what is lost every hour one of these huge vessels is out of service, would look at a proposition involving dozens of by no means small cylinders, very many turbochargers, scores of valves to maintain, and so on when he could meet his needs with two commonplace water-tube boilers and a set of two-casing main turbines? Where is there a Pielstick multi-engine installation of even 10,000 s.h.p. to show us that these bold ideas are practical? As I write I have at my side a reprint from a German shipping journal of almost two years ago which shows a three-bank (and three-crank) Pielstick engine with twenty-one cylinders. Each cylinder (400 mm. by 460 mm.) is capable of developing a maximum of 333 b.h.p. per line at 520 r.p.m. The Pielstick is a nice four-stroke design evolved by a man of ripe experience and high reputation; but to produce somewhat less than 7,000 b.h.p. at the main gearwheel coupling with a fair amount of complication—including three crankshafts and reduction gear pinions—is not a recommendation for the scheme; two such engines with the gearing between them would give a reasonable shaft output at the expense of considerable complication. A direct-drive engine is preferable. Turning to your own journal for May, 1954, I see you give a more conservative service rating for this arrangement—as little as 5,250 b.h.p. at 425 r.p.m.—and the weight with gearing and thrust block is said to be 126 tons. This interesting set has not yet gone to sea and I have not seen any reference to the ship into which it is to be fitted.

MULTITUDE OF COMPONENTS

Such a power is a long way below what would be possible with some of Pielstick's interesting schemes and it is disappointing that his bold ideas have not been taken up. He has designs available for pressure-charged engines with up to 24 cylinders of the size mentioned on a single crankshaft; this gives 8,000 b.h.p. (maximum) at 520 r.p.m. Four such engines grouped around a gearbox and using the elastic couplings developed for such installations would provide a single-screw plant with a continuous-service rating of rather more than 23,000 s.h.p. at the shaft coupling, making reasonable allowance for gearing losses. This would meet future needs but it would be obtained at the cost of mechanical complexity of no mean order: 96 cylinders, 384 valves and so on. How many operators of present-day high-cost, hard-worked tankers would adopt such an admittedly advanced but complex plant in preference to a set of geared turbines? And how many engineers would be prepared to stay with such an installation?

GEARED PROPOSALS

It very much looks as though the diesel makers have been caught napping in a surprising fashion since the war. With their advance knowledge of likely requirements in the light of rising size and power, they have done little to be ready for the needs of owners. Too little too late is a phrase we have heard in another context, and it applies to this case. I am surprised that the leading marine oil engine firms did not see the desirability—is necessity too strong a word?—of developing geared diesel drives more seriously. True we have seen a few installations of moderate power per shaft completed for cargo ships, but nothing has been built for merchant vessels of a power per screw higher than can be met comfortably with a directly-coupled standard engine. Further than that, all these installations make timid use of engine speeds which are far too low if the best results are to be obtained with geared drive. No wonder the pundits say there is "nothing in geared diesel drive!" And this at a time when the turbine people are using 8,000 r.p.m. rotor speeds, modern conceptions of double-reduction gears, yet higher steam conditions and various other advances which are successful.

Although these geared diesel installations have not really demonstrated anything it must surely be clear to every engine manufacturer that geared drive, boldly conceived, *could* provide the answer to the steam turbine. Few of them have shown any serious interest in it. In fact, two of the leading marine diesel specialists—Burmeister & Wain and Doxford—have taken no part in the rather tentative moves we have seen. It is not in the best interest of themselves, their many licensees, or their even more numerous cus-

tomers, that they have no experience with geared installations at the present time.

Britain has several suitable engines for *real* geared installations. I would single out the Mirrlees Vee engine, a modern, four-valve diesel of straight-forward design which, it has been demonstrated, can run reliably with high mean pressures and, by direct diesel standards, high piston speeds. It is designed for operation with high-pressure-ratio pressure charging. Four such engines, each of about 4,100 b.h.p. continuous-running rating, running at 428 r.p.m. would provide a really up-to-date plant, using hydraulic or magnetic couplings and hardened and ground reduction gears. It would be light and compact and would be a worthy competitor for the geared steam turbine up to moderate shaft power limits. Other engines could be instanced but I mention the Mirrlees because it is the highest-power suitable British design. If real power is needed, on the other hand, there is the 7,703 b.h.p. at 400 r.p.m. V-16 engine to which you referred in your interesting September leading article. This is the Enterprise engine—you did not give the name—and it seems to be a straightforward design without any frills. Whether it would be prudent to run it continuously at a power approaching the figure quoted might be questioned, but it is an intriguing thought that with it a four-engine geared installation of 25,000/26,000 s.h.p. seems within the realms of practical politics. It is worth remembering, too, that this is a *four-stroke* turbocharged direct-reversing engine with pistons of 13 in. and other parts of manageable weight and size.

CONCENTRATED DELTIC POWER

The ultimate in diesel installations is, of course, not represented by the above. Who will give the remarkable Napier Deltic a chance to show what it can do in a merchant ship? The Napier firm have proposed exhausting their three-crank opposed-piston engine into a gas turbine neatly accommodated inside the delta. Powers comparable with those of the Mirrlees engine should thus be possible with a smaller and lighter installation having yet smaller and lighter moving parts. A geared plant with such compound engines would have to be operated on the replacement engine overhaul-them-ashore plan and there is no reason why such a scheme should not work. I see from papers given in the States by Mr. E. Chatterton, the chief engineer of Napier's diesel department, that the maximum rating for this interesting engine, based upon 5,000 hours between piston withdrawals, would be 3,850 b.h.p. On this conservative rating the claimed weight would be 2.8 lb. per b.h.p.! The author also showed a geared proposal for 10,000 s.h.p., using six eighteen-cylinder Deltics—three forward and three aft of the central gearbox. The overall length of the installation as shown in this author's 1955 St. Louis paper is about 32 ft. and its weight 65 tons. The corresponding directly-coupled low-speed installation would, the author contends, need an engine room length of 65 ft. against the 39 ft. of the Deltic plant, and the weight of the former is estimated at 450 tons which is not high. If compound Deltics were used the total engine power (continuous rating, but without allowance for gearing, etc., losses) would be 23,100 b.h.p., or just about the s.h.p. requirements of one of these big vessels.

By all accounts noise is the great drawback to the Deltic, largely blower noise. That should not prove an insuperable difficulty; and why not enclose the engines in acoustic cabinets like the air-cooled auxiliary engines in the little coaster you described earlier in the year? Your comments indicated that you were really impressed by the results.

WHAT IS THE DIESEL ANSWER?

To sum up, the diesel camp seem to have lost their grip on the high-power single-screw situation, especially during the past five years while they have been busily developing turbocharging for large two-stroke single-acting engines. As things stand at the moment they have, it seems, arrived at the position where they can confidently offer what was required, in large measure, *before* they took up two-stroke, turbo-charging. They have no real answer for the power requirements of the present stage of tanker development. The steam people have, and they are ready for the next stage. Isn't it time the diesel builder got down to using some bolder ideas? It is not rubbing it in too much to remind readers that the cylinder powers being achieved commercially today are little higher than were reached before the war. In fact, *experimental* single- and double-acting two-strokes of 2,000 b.h.p. per cylinder were run with varving degrees of success a good many years ago. Vickers had a single-cylinder single-acting engine of this power on test at Barrow before the first war, and among the several high-powered experimental two-stroke engines built by Sulzer Bros. was one of 1,000 mm. cylinder diameter. These are mentioned as being among the more notable achievements but, as is known, all "parent" firms in the large marine oil engine business have built these high-output experimental engines. This was done without the benefit of turbocharging.

As the position has developed it looks as though the 20,000/22,000 b.h.p. low-speed turbocharged single-acting two-stroke engine is essential if the challenge of steam is to be met really effectively. The alternative—a good one, correctly done—is indirect drive. If the Doxford low-speed engine is to meet this requirement it would seem that an output per cylinder of about 3,500 b.h.p. would be needed, assuming that the torsional vibration problems of the seven-cylinder engine remain unresolved. This output seems beyond the practical limit of the type—or of any other rival engine—and it is hoped that the new Doxford design to which you have referred will be available in medium-high-speed form for use with reduction gearing. The more conventional engines with one crank per cylinder seem to be better placed

for these high powers; a twelve-cylinder engine of 1,750 b.h.p. per line in service could give us the 21,000 b.h.p. which would meet the powering needs of many of these large vessels. A ten-cylinder 20,000 b.h.p. engine would, however, be preferred by many.

It might be suggested that there is a case for a return to the double-acting engine. Technically this is so, but most superintendents and operating staffs prefer the easier, quicker and cheaper overhauling of the simpler single-acting engine. (The Doxford engine is outstandingly good in this important respect, and such engines as the Werkspoor-Lugt and latest Sulzer are also extremely well designed from the operator's standpoint.) Few owners would like to go back to double action, even if it meant slightly smaller main components; it should be possible to meet powers of the order just mentioned with single-acting engines.

For higher powers than 20,000/22,000 s.h.p. there seems little likelihood of the directly-coupled diesel engine filling the bill, and it seems over-sanguine to think that technical progress with these large low-speed engines will ever make higher continuous-rating powers possible. Higher powers clearly lie with indirect drive, either with reduction gearing, diesel-electric drive, or a combination of the two such as America has used with success for moderate powers. On the other hand the gas turbine may prove to be the effective answer to the geared steam turbine in due course.

Dewline, a joint Armed Services operation in 1955 under the direction of the Military Sea Transportation Service, was the largest sea transportation job ever attempted beyond the Arctic Circle. It represented the first opportunity to field test propellers of nickel-aluminum-bronze alloy in frigid waters and under hazardous ice-floe conditions. Twenty-two of the 88 ships involved were fitted with propellers of this alloy which were made by Baldwin-Lima-Hamilton Corporation. The new alloy's performance record was good and there was no evidence that the low temperatures had any deleterious effect on the material.

JOHN FLODIN

FIXATION OF BEAMS IN VIBRATION CALCULATIONS

THE AUTHOR

earned his BS in mechanical engineering and later his ME degree, University of Washington, Seattle. Taught mechanical engineering at the University of Minnesota, 1923–'31, during which time he was awarded the MS and MA degrees. Engineer at the New York Naval Shipyard and at the Bureau of Ships, specializing in deck auxiliary machinery, 1932–'41. Assistant chief engineer, Lidgerwood Manufacturing Co., Elizabeth, N.J., 1941–'46. Taught mechanical engineering, University of Maryland, 1946–'48. Currently consulting engineer, Washington, D.C. Contributions: numerous articles published in commercial engineering and other magazines; chapter on Deck Auxiliary Machinery in Volume 2, Marine Engineering, published by the Society of Naval Architects and Marine Engineers.

VIBRATION CALCULATIONS are ordinarily made for the purpose of avoiding synchronism of the natural period of vibration of a structure or its analogous beam and the known or desired speed of rotation of a machine, and since the calculations are likely to be complicated a generous allowance for error is made, often as high as ten per cent.

In finding the natural period of vibration of a beam or of its analogue, the first step is to find the deflection under a given load, and this in turn involves deciding on the length of the beam and the manner of supporting or fastening its ends. There is rarely much difficulty in deciding on the length of the beam with reasonable accuracy even where brackets or gussets are used at the ends, but care and judgment must be used. The manner in which the ends are supported or fastened requires greater study.

The beam shown in Figure 1 is freely supported and is subjected to a concentrated load at its center. Here the deflection is given by *

$$D_{max}=\frac{Ff^3}{48EI}$$

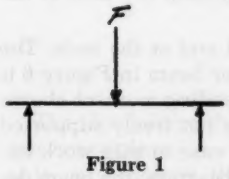


Figure 1

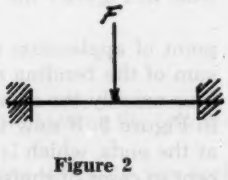


Figure 2

The beam shown in Figure 2 is supposedly fixed at both ends and is again subjected to concentrated load at the center. The deflection is given by

$$D_{max}=\frac{Ff^3}{192EI}$$

The ratio of these two deflections is 4 to 1, an enormous difference in view of the possible ten per cent allowance.

The beam in Figure 3 is freely supported at both ends and is subjected to a uniformly distributed load of ω per unit length. The deflection is given by

$$D_{max}=\frac{5\omega f^4}{384EI}$$

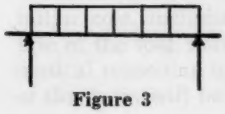


Figure 3

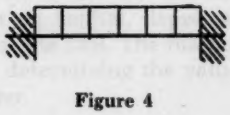


Figure 4

* Derivation of these formulas may be found in any textbook on strength of materials. The symbols are those commonly in use: F=concentrated load; ω=uniformly distributed load per unit of length; f=length; E=modulus of elasticity; I=moment of inertia; D=deflection.

The beam in Figure 4 has firmly fixed ends and is also carrying a uniformly distributed load ω per unit length. The deflection is

$$D_{max}=\frac{\omega l^4}{384EI}$$

The ratio of the last two deflections is 5 to 1, again an enormous difference, larger by one-fourth than the ratio found above for concentrated loads. Both comparisons show that it is possible to make a grossly significant error at the very start of the calculations, and it is the object of this article to suggest a way for at least minimizing the error.

COMPENSATING FOR LACK OF ABSOLUTE FIXATION OF ENDS OF BEAMS

Figures 5 and 6 show the same beams as in Figures 1 and 2, respectively, with the bending moment

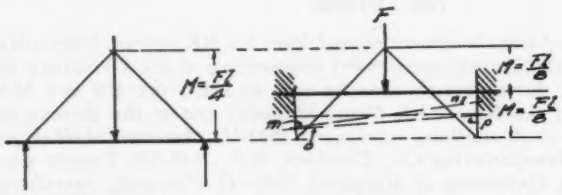


Figure 5 Figure 6

graphs added. In Figure 5 the maximum bending moment is shown to be $\frac{Fl}{4}$ at the point of application of the load. In Figure 6 the bending moment is $\frac{Fl}{8}$ both at the point of application of the load and at the ends. The sum of the bending moments for beam in Figure 6 is thus exactly the same as the bending moment shown in Figure 5. If now the beam is not freely supported at the ends, which is never the case in ship work except in cases of shafts in roller bearings, the beam departs from the condition shown in Figure 5 but will not reach the condition shown in Figure 6 since no beam is ever fastened at the ends with absolute rigidity. We have therefore a degree of fixation of fastenings differing from both these extreme cases, and which may not be the same for both ends. The broken line in Figure 6 drawn parallel to and below the beam indicates a case where both end fastenings are judged to be midway between freely supported and rigidly fastened. In this case the bending moment at the load becomes $\frac{3Fl}{16}$, and we are justified in accepting the deflection as $\frac{F\,l^3}{120EI}$, that is, midway between the deflections for a freely supported and an absolutely fixed beam. Broken line **mn** indicates a beam where one end is judged to be 25 per cent fixed and the other 75 per cent fixed, giving the same deflection of $\frac{Fl^3}{120EI}$ at the load. Broken line **op** assumes 25 per cent fixation at one end and 50 per cent at the other, giving a different bending moment and therefore a different deflection, in this case $M=0.203\ Fl$, $D_{max}=0.0148\ \frac{Fl^3}{EI}$

Figures 7 and 8 show the same beams as in Figures 3 and 4, respectively, with the bending moment graphs added. In Figure 7 the total height of the bending moment graph is $\frac{\omega l^2}{8}$. In Figure 8 it is $\frac{\omega l^2}{24}$ at the center and $\frac{\omega l^2}{12}$ at the ends, giving a total height of the graph of $\frac{\omega l^2}{8}$, or the same as for Figure 7. We can therefore again have new reference lines for different conditions of fastening at the ends. Lines have been drawn corresponding to those in Figure 6 and similarly marked.

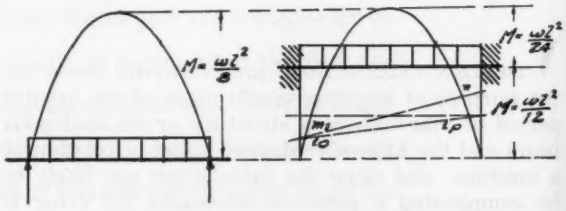


Figure 7 Figure 8

Like reasoning and like adjustments may be made in cases of other loadings, resulting in better accuracy in finding the deflections and therefore in the vibration calculations.

The one difficulty in applying this reasoning lies in the proper evaluation of the degrees of fixation of end fastenings, a problem for which neither rules nor formulas can be given. But certainly, in the absence of tests, even a good guess as to the degree of fixity of an end fastening will give more nearly correct results than if idealized textbook formulas are applied blindly and without correction.

"MECHANICAL ENGINEERING"

HOW TO ANALYZE THE COST OF MACHINE TOOLS ... From the Swivel Chair

ACKNOWLEDGEMENT

Realf Ottesen, Senior Designer, McCulloch Motors Corporation, Los Angeles, is the author of this article, published in the November 1956 edition of "Mechanical Engineering." The author was formerly in charge of research for Motor Engine Manufacturers' Research Institute, Trondheim, Norway, and the published article is a condensed version of a paper presented at the Semi-Annual Meeting of The American Society of Mechanical Engineers, in Cleveland, Ohio, June 17-21, 1956.

SOME YEARS AGO the author was faced with the problem of setting up general rules for the retooling program of many Norwegian motor-manufacturing plants. To avoid subjective arguments and to place general limits on the factors involved in deciding whether or not a new tool should be procured, and also to select the proper replacement tool, the author found it wise to treat the whole subject in a mathematical way. This proved especially useful in those cases where many varied production methods and machines are employed to complete the desired product. Furthermore, mathematical terms enjoy an ever-increasing popularity in these days when we are getting accustomed to employing elaborate computers on a wide scale. The analysis led finally to a simultaneous equation which for the sake of reproducibility was transformed into a nomographic chart with the aid of which the individual figures could easily be gathered and put together. The term "from the swivel chair" refers to the fact that this chart can be handled from the desk, and so allows the manager to select a suitable future tool, and also lets him survey his whole setup as to the plant's cost level and efficiency.

BASIC IDEA

The idea behind this scheme is based on the following assumption:

In any factory the production force is the tool which machines the assumed product plus the laborer who spends his hours at the tool to bring it into the desired shape. Here we have two sources of cost, such as the cost of the tool per hour and the wages of the laborer per hour. The tool costs a certain initial amount at its purchase, then is depreciated through a certain sequence of years while the laborer demands his hourly wages. Even if the tool is completely automatic the cost for the depreciation of the tool still remains.

Coming now to the main point of this reasoning, an attempt is made to condense all possible production costs to one term:

This term includes the cost of the tool in dollars per hour, direct labor costs, indirect labor costs, and other costs. Included in the cost of the tool are the initial cost, including interest on capital, depreciation of the tool, maintenance of the tool. The mathematical reasoning involved in determining the value of this term will be shown later.

TABLE 1—*Nomogram Data*

	Item	Dimension
Initial cost	A	$
Depreciation factor	a	%
Space requirement	q	sq ft
Specific cost of floor space	b	$/sq ft
Cost of energy (current)	s	$/kwhr
Power consumption	p	kw/hr
Utilization factor	X	hr/year
Total debit cost per hour	D	$/hr
Direct hourly wages	t_1	$/hr
Indirect hourly wages	K	$/hr
Unproductive wage factor	z	$/hr

We all know that the reason for contemplating the purchase of a new machine is either to cut production costs or to increase production. In cases where the desire is to cut production costs, the proposed tool is to be used to replace a worn-out tool which is no longer doing its job, or the new tool is a modern one which does the job more efficiently than the old obsolete tool. In most cases where a new tool is to be purchased there is a wide choice of tools from which to choose which will do the job. Provided we dispense with all individual feelings, such as the more or less famous make of the tool, its reputation, its appearance, and the like, there remain the following basic questions:

1. What is the initial cost of current tools?
2. How do the costs of the tools compare with those of my competitors' tools?
3. What price level has the tool to be loaded with for no profit and with certain profit conditions?

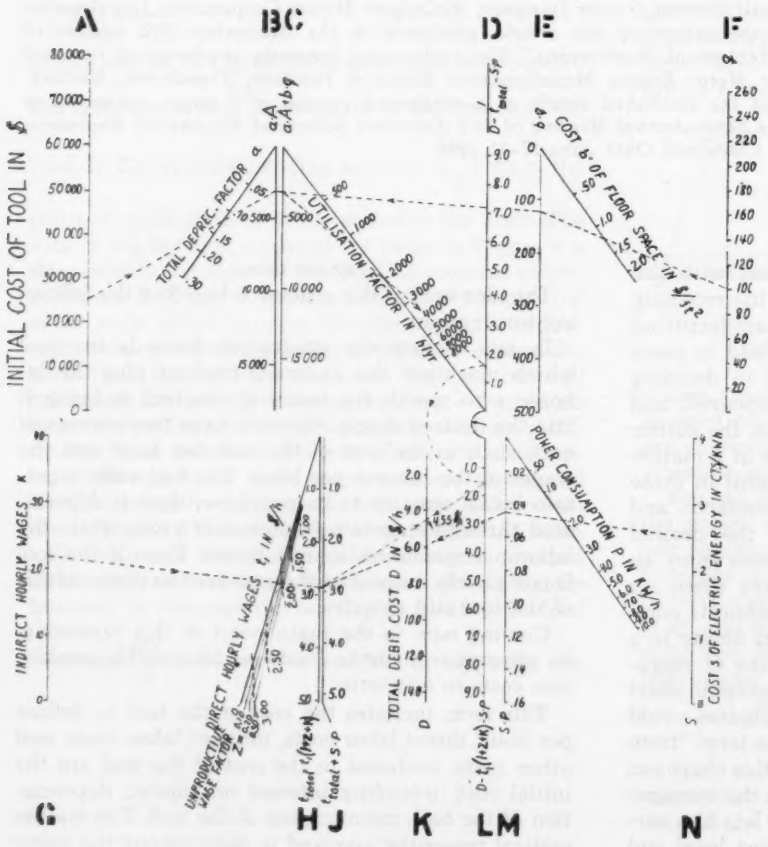
These questions can be resolved by applying the data given in Table 1 to the nomogram, Fig. 1.

The author will try to give a solution for all these variables as it is the aim of this treatise to stay within the bounds of dollars and cents by not using a subjective view which sooner or later always winds up in differences of opinion. From the first moment this aim will seem confusing. The whole problem, however, will appear more susceptible of solution if we start out by assuming the utilization factor as a function of annual expenses for the tool against the hourly expenses, which gives the following equation

$$\text{Utilization} = \frac{\text{annual expenses in \$/yr}}{\text{hourly expenses in \$/hr}}$$

The final result is in hours per year.

How we arrive at the specific mathematical terming of this equation will be shown in the following.



$$D = \frac{aA + bq + X[t_1(1 + z + K) + sp]}{X} \text{ in \$/hr}$$

$$X = \frac{aA + bq}{D - t_1(1 + z + K) - sp} \text{ in hr/yr}$$

where

A = initial cost ..... in $
a = depreciation factor plus 2/3 of rate of interest plus rate of repair work
q = space requirement ..... in sq ft
b = cost of floor space ..... in $/sq ft
X = utilization factor ..... in hr/yr
D = total debit cost ..... in $/hr
t_1 = direct hourly wages ..... in $/hr
K = indirect-hourly-wage factor
z = unproductive wage factor
s = cost of energy ..... in cents/kwhr
p = power consumption ..... in kwhr

Example: Precision Boring Mill

A = $25,000
a = 0.1215
q = 100 sq ft
b = 1.25 $/sq ft
X = 2000 hr/yr
t_1 = 2.20 $/hr
K = 0.22
z = 0.10
s = 2.5 ct/kwhr
p = 1.8 kwhr
Result: D = 4.55 $/hr

Figure 1. Nomographic chart for analysis of cost of machine-tool operation.

ANNUAL COST AND DEPRECIATION FACTOR

It is not the aim of this paper to give a thorough analysis of the varying ways which decide the proper calculation of the depreciation factor. The following points, however, may help in summarizing this problem, although they are very well known everywhere in management. In the calculations any depreciation appears as a cost. In some cases, and especially when the balance of the year is in excess of expectations, there can be ordered extraordinary write-offs. This results in a decrease of the annual write-offs in later years. In extraordinary cases some tools may be depreciated to a low value of, for example, $1.00. In this case no further deductions for depreciation would be made in the books. However, when calculating the cost of production, it wouldn't be fair to debit the product with excessive depreciation for any particular year. These calculations once made up should be followed as long as the tool is being used and regardless of the possibility that the books will show differently. This procedure will be followed in this scheme.

Refinancing New Tools

Any amounts for depreciation are designed to refinance the purchase of a new tool. Therefore it is essential that there is enough capital on hand to procure a new tool considering the actual price of this new tool at the time of purchase. For this reason it is sometimes necessary to make allowances for fluctuations of prices in the open market. A careful management will always desire to follow any price fluctuation in the market, especially its effect on the cost of a new tool. As it is furthermore commendable to correct the amount of depreciation at least once a year, the management has the assurance that the depreciations made during a sequence of years surely will buy a new tool in due course.

The depreciation factor usually is termed in percentage of the value of the tool whether the price is the initial cost or the actual price of the tool. For an ordinary tool the depreciation time can be stipulated by 10 years and the depreciation factor is then 10 per cent or 0.10. It goes without saying that these factors have to be adjusted to the practical results. In case the tool in question shows heavy wear, the depreciation factor has to be increased and vice versa.

Cost of Repairs

In addition to the depreciation factor there is the cost of the repair work. This is entirely a matter of experience and routine which every manager knows to close tolerances. Usually the cost for repair is almost nonexistent in the first years but picks up at an increasing rate in later years. In order to equalize an almost constant depreciation factor and a gradually increasing repair factor it would be most desirable to operate with as equal a combined factor as possible.

It is somewhat difficult to state the correct figures concerning depreciation factors as these are matters of personal judgment and experience, and furthermore must be agreed to by the Bureau of Internal Revenue. Machine tools which are the subject of this paper will range between 5 and 10 per cent. Furthermore it must be decided whether a machine tool is fully satisfactory as to competing qualities or, maybe, has to be replaced much earlier in order to give way for a more effective and cost-saving one. With these remarks we can consider the matter of depreciation as settled.

Interest Charges

Another point to be remembered is the calculation of interest charges. In many cases and especially where the production facilities are being extended, the management has to take up a loan for the purchase of new machine tools—and has to pay a certain rate of interest. Some specific remarks about this are in order.

If an outside loan has to be established, naturally the lender charges a certain rate of interest which then remains as a firm cost for the factory until the loan is paid back. This cost for the interest consequently must remain part of the production cost.

Provided the capital comes from the plant's own funds, this also has to be subject to interest charges if the structure of the factory is to remain sound. It is an ironclad rule that capital which can be disposed of should bring interest back into the plant. If the plant were unable to provide interest on its own capital, the stockholders would be at a loss, and this is an unhealthy development as a management that has come into this serious position would experience considerable difficulty in raising any additional funds. Yet it may be stated here that a company should prefer to use its own capital and pay interest to itself because any outside lending agency will demand some sort of security—usually the plant's assets—and in case of bankruptcy such agency is entitled to repayment ahead of the stockholders. It is, therefore, not only commendable but also strongly advisable that the management make allowances for these interests in all cost-accounting methods, whether its own or outside capital is involved.

Estimating Interest

The originally invested capital is the price at the date of the machine-tool purchase plus the cost of duty, freight, erection, and so on. Let us assume that the price of a tool is $25,000. A 5 per cent interest on top of this figure would amount to $1250—for every year. This cannot be correct as no provision has been made for the depreciation during a sequence of years. This method would be proper when all depreciation sums would be put into a bank account, and the interest from this account would be deducted from the original value of the tool. As it is, nobody would act like this. Instead, the amounts owed to depreciation are usually invested in the same enterprise from which they came. In case we would estimate interest of these new assets again on top of the formerly mentioned assets we would suddenly have

to face the fact that we estimated interest from both assets, which sounds absurd.

For the sake of simplicity and for the purpose of obtaining a practical and appropriate solution, there exists the possibility of multiplying the rate of interest—here called c—with a factor like ⅔ wherein c remains the rate interest for the whole period depreciation is in effect. By this means we avoid overdimensioning the interest procedure as just explained. Thus assuming, e.g., that the rate of interest is 4.5 per cent we only account constantly for ⅔ × 4.5 = 3 per cent. For the final analysis of the total cost of machine tools we will avail ourselves of this method.

Previously we had mentioned the yearly cost for repair work. As the factor of depreciation and the rate of interest are suitably expressed in percentage this should be the proper term for the factor of repair work g. In order to make the final nomogram most applicable this factor will be set arbitrarily at 2 per cent constantly.

The final estimate for depreciation, interest, and repair work will assume the following shape:

The total depreciation a will consist of the following factors

$$a = f + \tfrac{2}{3}\, c + g$$

where

f = factor of depreciation
c = rate of interest
g = factor of repair

This factor a multiplied by the total price of the new tool gives the yearly amount of depreciation.

The reason for having given these well-known facts a somewhat detailed explanation will be fully understood later when it has been shown that the total amount for depreciation has a somewhat dominating influence upon the production cost.

COST OF UPKEEP

As soon as the amortization plan comes into effect any machine tool will start running current expenses for upkeep, such as rent of floor space, heating, light at tool and in shop, insurance, electric energy, and so on. The last mentioned item will be treated separately.

In order to find a mutual base which facilitates a specific estimate of these current expenses, it is suggested here to convert these into cubic feet of shop volume or better into square feet of shop area. The latter method seems to be the most suitable one inasmuch as most of the modern factories consist of one-story buildings where the distance from the floor to ceiling remains uniform. This makes the shop volume identical with the floor area. Thus it seems appropriate to correlate the cost of upkeep for a tool with relation to the floor space it covers.

Estimating Floor Space

When listing the space in square feet of a machine tool, the following items must be taken into consideration:

(a) The space requirement of the machine itself comprising all the tool's movements in a horizontal plane.

(b) Space for the machine goods awaiting their turn.

(c) Space for the laborer, his tools, and tool chest.

(d) Additional part of the unused space of the factory premises, eventually proportional space of office and all indirect space.

The practical procedure will be the following:

At first the direct space for the machine tool will be calculated according to (a); thereafter an additional space of approximately 30 sq. ft. will be added according to (b), and another 20 sq. ft. for the laborer himself. Finally the proportional space according to (d) will be added. The total space requirement will be termed q and the dimension is in square feet.

Current Expenses

While these details easily can be listed as they are a basic part of the factory organization it is somewhat more difficult to ascertain the cost of the current expenses for a machine tool. There the experience of the management and the production engineer will be helpful. The following figures are approximate for such a calculation:

Total rent of space	17q
Heating	8q
Ventilation	2q
Overhead light	4q
Light at machine tool	4q
Insurance of tool	1q
Diversified	4q
Total	40q ($/year)

It will be evident that these figures will vary considerably in different factories. If we were to make a serious mistake in calculating the rent and maintenance cost, this error would not have disastrous effects in the final analysis as the cost of depreciation is so much greater that the costs just mentioned will only influence these costs in a minor degree, as will be proved in an example later. On the other hand it would not be wise to disregard even minor expenses considering that there are installed a multitude of machine tools even in an average-sized factory. Obviously such an error will multiply any mistake in the estimates by its numbers.

Influence of Wage Factor

In the previous paragraphs we have discussed capital values which can be calculated rather simply. On the surface it would seem that the calculation of the influence of the wage factor on the production cost would be a more complicated task. However, this can be broken down into two major factors, type of machine tool, and general expenses of the factory. Thus to calculate the total debit cost per hour (D = $/hr.) we must know the following:

Direct hourly wages	t_1 in $/hr.
Indirect-hourly-wage factor	k
Unproductive-hourly-wage factor	z

The total debit cost per hour (D) tells the management the nonprofit price of production in \$/hr. for any particular machine. The direct and indirect wages should then be converted to the same units; that is, \$/hr. Other direct costs are those covering the material consumed or machined during the manufacturing process and the cost of energy. Cost of material can easily be traced separately and therefore can be excluded from the problem at hand. The most important direct cost is represented by the direct labor wages in \$/hr. which adds directly to the cost of the machine tool. In any factory there occur many forms of indirect wages, such as wages for foremen and general shop people, wages for office employees, and so on, general expenses as postage, telephone, insurance, fringe benefits, cleaning, and the like. All these expenses have to be taken into account remembering that all wages should be expressed in \$/hr. These, of course, have to be debited to the direct wages. This seems quite logical inasmuch as the work produced by the machines represents the bulk of a factory's earning power.

APPLYING THE METHOD

In the following paragraphs an attempt will be made to compose a working scheme for any structure of a machine factory, large or small.

Provided the direct wages per laborer are termed t_1 (\$/hr.), or T (\$/year) and one year represents 2000 working hours the yearly wages per laborer will amount to

$$T = 2000 \times t_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots [1a]$$

The indirect expenses can be divided into:

(a) Wages for office employees per year, L_1 (\$/yr.).

(b) Vacation pay for laborers, and fringe benefits, and the like.

(c) Unproductive expenses; e.g., for administration and its branches.

Assuming that the number of laborers is a, the wages of these laborers are

$$L_2 = 2000 \times a\, t_1 \text{ (\$/yr)} \quad \ldots\ldots\ldots\ldots [1b]$$

At this stage it has to be decided what type of factory is being dealt with.

It might be a small factory making screws on automatics, or it might be a motor-engine factory with considerable research facilities which will require a large staff of highly trained engineers. These conditions can be taken care of by establishing an indirect wage factor K

$$K = \frac{\text{indirect wages}}{\text{direct wages}} = \frac{L_1}{L_2} \quad \ldots\ldots\ldots\ldots\ldots [2]$$

which factor will tell clearly about the structure and general scheme of the factory in question.

It goes without saying that this factor K should be kept low as the indirect wages are charged to the direct ones. Concerning a certain branch of manufacturing the indirect wages are supposed to remain in a certain relationship relative to the number of laborers, in which category laborers are considered as those who do productive work such as attending to the tool machines, erecting machinery, and so on. This relationship, of course, must not differ much in the organizational scheme of manufacturers making the same products. It is enlightening to analyze this factor K for the most diversified fields of manufacturing. This, however, will not be discussed at this time as it does not deal directly with our topic and space is limited.

A multitude of examples shows that the factor K in 90 per cent of all cases lies between 0.20 and 0.28. Furthermore, the factor is a major function of the laborers' wages as it increases with lower wages and vice versa. This phenomenon, however, is not directly applicable as it is a fact that in areas with low direct wages also will be found low indirect wages. The relatively narrow limits of the factor K in most instances permits us to assume $K = 0.24$ for approximate estimates without making any calculations. This will hold true for any plant which has a sound financial structure.

The indirect wage factor K also can be determined by the following equation

$$K = \frac{\frac{L_1 + L_2}{T_1} - t_1}{t_1} \quad \ldots\ldots\ldots\ldots\ldots [3]$$

where $T_1 = 2000\ a$; a = number of productive laborers.

If we call the indirect hourly wages

$$t_2 = K\, t_1 \quad \ldots\ldots\ldots\ldots\ldots [3a]$$

then

$$t_2 = \frac{L_1 + L_2}{T_1} - t_1 \quad \ldots\ldots\ldots\ldots\ldots [4]$$

The part of the wages t_3 which corresponds to the vacation pay of the laborers is

$$t_3 = \frac{100\ a\ t_1}{T_1} \text{ and with } T_1 = a \times 2000$$

$$t_3 = \frac{100\ a\ t_1}{a \times 2000} = 0.05\, t_1 \quad \ldots\ldots\ldots\ldots\ldots [5]$$

In addition to these expenses another source of cost must be calculated which is called here the unproductive wage factor y consisting of fringe benefits, postage, telephone, cleaning, building repair, and the like.

This part t_4 of the wages will then be

$$t_4 = y\, t_1$$

(For preliminary survey of the total cost this factor y can be set at 0.05.)

The total hourly wages t_{total} assume then the following equation

$$t_{\text{total}} = t_1 + t_2 + t_3 + t_4 \quad \ldots\ldots\ldots\ldots [6]$$

$$t_{\text{total}} = t_1 + \left(\frac{L_1 + L_2}{T_1} - t_1\right) + 0.05\, t_1 + y\, t_1 \quad \ldots\ldots [7]$$

or

$$t_{\text{total}} = \frac{L_1 + L_2}{T_1} + (0.05 + y) t_1 \quad \ldots\ldots\ldots\ldots [7a]$$

Let the term $(0.05 + y) = z$; then z represents the combined unproductive wage factor. Thus our Equation [7*a*] reduces to

$$t_{total} = t_1 (1 + z + K) \quad \ldots\ldots\ldots\ldots [7b]$$

The total debit cost per hour is reduced by t_{total} and the cost of energy ps consumed, wherein p represents the average power consumption in kilowatts and s the specific cost of energy in cents/kwhr. Provided it is necessary to establish the average cost of energy per hour for a machine tool having intermittent power consumption, then the only way to average this cost is to make proper time studies for an actual machining process. This procedure, however, is often complicated unless the management uses modern production-engineering methods and prescribes a detailed working scheme for most of the tools. Provided the cost of energy remains an essential part of the cost such as for electric hand tools, it is advisable to connect a recording wattmeter to the circuit of the tool and thus average the power consumption for some length of time. In other uses where the power consumption is of less importance this cost can be estimated easily.

A profit V any tool makes can be expressed as follows

$$V = D - t_{total} - ps \quad \ldots\ldots\ldots\ldots [8]$$

This equation will give the profit in the unit \$/hr. which decidedly is an advantage.

The final utilization factor X which decides the number of hours per year in which a tool has to be worked in order to pay for itself after a sequence of years can then be expressed by the following equation

$$X = \frac{aA + qb}{D - t_1(1 + z + K) - ps} \text{ hr/yr} \quad \ldots\ldots\ldots\ldots [9]$$

By transforming Equation [9] the total debit cost per hour (D) can be decided by

$$D = \frac{aA + qb + X[t_1(1 + z + K) + ps]}{X} \text{ \$/hr.} \quad [9a]$$

Equations [9] and [9*a*] have 10 variables which can be divided into variables belonging to the basic tool such as a, A, q, p while the other variables belong to the shop itself, such as b, t_1, $(z + K)$, s. For a certain machine shop the variables b, t_1, $(z + K)$, and s are constant for all tools under that period where no major changes are being made in the shop's basic organization.

For a machine tool the variables A, q, p can be taken from a catalog. The depreciation factor a has been discussed before and can therefore be decided accordingly. The initial cost including additional tools, insurance, freight, and erection can be estimated easily. The only uncertain variable is the power consumption which has been mentioned previously. In order to demonstrate the application of Equations [9] and [9*a*], respectively, let us calculate a machine tool accordingly.

USING THE NOMOGRAM

Equations [9] and [9*a*] are not so practical for shop use. They are, therefore, presented in a nomographic chart, Fig. 1, which gives the proper solution for all 10 variables. The nomographic chart is designed in such a way that the numerator of Equation [9] remains on the upper part of the nomogram while the calculation of the denominator is performed in the lower part of it. Typical for the nomogram, furthermore, is that the analysis operation can be started from any part of the chart until finally the axis is reached which gives the value of the unknown variable. Another advantage of the nomographic chart is incorporated in the fact that even in those cases where the exact factors are uncertain the operation still can be performed by using a limit of the unknown factor and thus wind through the chart with two values of a factor. The result will then show two values due to the limiting of an approximate factor.

A line drawn from the scale A to the value of the depreciation factor will multiply these two values on scale B. This point has to be marked. Moving to scale F a line is drawn through the scale of the cost of floor space which will give the product of this multiplication on the scale E. The points of scales B and E are now connected and perform an additional process on scale C. This new point on scale C is connected with the proper utilization factor and is projected to scale D. The distance of this point of intersection from the origin O is then transferred to scale L by the arc of a circle about the origin O. The scale L gives the reciprocal value of scale D. The new point on scale L is marked again while the rest of the operations are going on. Choosing K on scale G and the direct wages t_1 as well as the unproductive wage factor z renders the total hourly wages on scale H which point also is marked. Moving over to scale N the value of the cost of the electric energy is connected with the value of the power consumption and projected to scale M gives their product in which both values are multiplied on scale M. The points on scale H and M are connected. This manipulation adds them on scale J. Finally, a connecting line is drawn from scale J to L which intersects scale K at a certain point which gives the true cost of the machine tool in \$/hr.

"GENERAL ELECTRIC REVIEW"

BEARINGS—HOW THEY'LL BE IN THE FUTURE

ACKNOWLEDGEMENT

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THESE DAYS the layman can easily conjure up a picture of the technological roadblocks imposed by the heat barrier. Almost a classic example by now is the intercontinental ballistic missile hurtling downward through the atmosphere at speeds on the order of 10,000 mph, its skin glowing white-hot.

But most engineers and scientists encounter more immediate problems than this. Right now, for instance, they are grappling with the problems of 500° F. temperatures generated on the surface of piloted aircraft moving at more than twice the speed of sound. For atomic power reactors—particularly airborne nuclear-propulsion types—control motors and other apparatus may be needed that will function at temperatures higher than 500°F. or in the neighborhood of 1000°F.

Like nearly all machines, somewhere and somehow these devices depend for their operation on the low-friction movement of surface passing surface. In other words, they depend on bearings. This was essentially true of the first wheel and axle. Today, the extreme loads, speeds, and temperatures of modern technology compound the present situation.

And tomorrow, the demands of an advancing complex technology will be even more exacting.

COMBATING FRICTION

Essentially there are only two kinds of bearings. The first and oldest—the sleeve bearing—is well-described by its name: the sleeve bearing fits snugly around an axle, as a sleeve fits around your wrist. Either the sleeve or axle rotates .Usually though, the axle moves as with the shaft of an electric motor.

Rolling-element bearings, typified by the ball bearing, are more recent mechanisms. Their rolling action reduces friction.

Because sliding friction is the source of most bearing problems, the fundamental phenomenon involved is worth describing.

All surfaces, even the most finely polished, have microscopic hills and valleys that mesh with the hills and valleys of opposing surfaces. Areas of actual contact between a polished shaft and bearing are thus small fractions of the apparent area. When the hills of shaft and bearing collide, unit loads get extremely high—so high, in fact, that temperatures reach the welding point. These microscopic welds may be broken as fast as they form, and in the process they may also tear out chunks of metal. Such an effect roughens the surfaces. Quickly this snowballs to catastrophic wearing or welding of the shaft in its bearing.

To reduce friction and prevent these failures, you must develop a barrier of lubrication between surfaces. If all shearing effects can be restricted to this layer of lubricant, no damage to either surface occurs. Accomplishing this calls for one of several techniques.

For one, you could develop a hydro-dynamic, or pressurized, fluid film that is thin but thick enough to keep surface irregularities from meshing. Such a film requires of its lubricant only that it have viscosity—resistance to flow. Subjected to high rates of shear, the lubricant develops back pressures that support heavy shafts on a thin film of oil.

Another technique is boundary lubrication. Here a chemical reaction at the shaft's surface forms a barrier layer of either oxide or another chemical compound having low shear strength. You can induce this reaction by adding reactive sulfur, chlorine, or phosphorus to the oil. (Inclusion of such additives in automobile lubricants, incidentally, made the spiral-like hypoid gear of your car's rear axle a practical success.)

Sometimes, natural components of the oil effect boundary lubrication. But whether natural or added components, usually mineral oil in some state of refinement forms the base fluid. These oils so well serve an extensive range of products that only a few mechanisms—your watch, for example—require special lubricants. Even now, selected mineral oils lubricate some of America's most widely used jet engines.

Ball, or antifriction, bearings demand less of a lubricant. Still, their requirements must be met. Contact areas between the balls and raceways aren't points as you might suppose: they are ellipses. (Even the hardest materials deform elastically under high pressure.) Over this small area some sliding occurs. Hence you need a lubricant. What's more, between the balls and their separators, or retainer pockets, some sliding also takes place, though at lower pressures.

LIMITS OF BEARING MATERIALS

Presently, the maximum temperature tolerable to bearing and lubricant materials at localized hot spots establishes the maximum loads, speeds, and ambient temperatures for most bearing systems. Many types of bearings reach this upper limit at about 250° to 300°F.

Other limiting factors are the lubricant's chemical and physical stability. They not only fix the upper temperature of a bearing system's operation but also complicate machinery design and manufacture. In short, you must make allowances for periodic lubrication with fresh oil or grease.

Today, in well over 90 per cent of industrial sleeve and thrust bearings, babbitt metal constitutes the bearing material. Invented by Isaac Babbitt of Boston in 1839, this material remains unsurpassed for excellent low-friction, antiscoring, antiwelding, and dirt-embedding qualities. (Babbitt metal is a soft alloy consisting largely of either tin or lead.)

The metal's upper temperature limit of 250°F., now being pushed, is reached in some gas turbine, automotive, and diesel applications. Thus you'll find a vigorous search in progress for higher temperature bearing materials. Such bearing alloys as aluminum, bronze, nickel, and also pure silver (Table I) are being currently applied in high-temperature applications. As yet though, none has proved as versatile as babbitt.

TABLE I

Temperature Limitations of Bearing Materials

Materials	Maximum Useful Temperature (Degrees F)
Journal Bearing	
Babbitt	250
Aluminum	400
Bronze	500
Silver	600
Nickel alloys	1600
Cobalt alloys	1600
Ceramics	2000
Rolling Bearing	
Special ball-bearing steel	400
Medium alloy steels	600
High alloy high-speed tool steels	800

Conventional steels used in ball and roller bearings have a similar temperature limit of about 250° to 300°F. With special heat-treating procedures, you can raise this limit to about 400°F.—still far from adequate in aircraft jet engines. Neither is this adequate for instruments, accessory drives, and other devices in missiles and rockets—nor for that matter, even in industrial units operating at high temperatures.

LIMITS OF LUBRICANTS

Present lubricants are limited at least as severely as bearing materials. The best petroleum oils you can obtain begin to oxidize rapidly at temperatures above 225° to 250° F. Varnish, sludges, and corrosive agents then form in the oil. What's more, these lubricants usually don't have the needed viscosity for the temperature range of −65° to +300° or 400° F. If they are thick enough at the high-temperature end, then they're too viscous at the low end.

In industrial devices, greases frequently lubricate ball or roller bearings. Greases—simply oil thickened with some gelling agent—such as soap—have the same temperature limitations as oils. In fact, they are even more restricted because both the gel structure and the fluid have to resist heat. Generally speaking, temperature limits of greases used in electric motors, instruments, and appliances are 50 to 100 degrees less than those of the fluid lubricants from which they are made.

A specific application will give you a good idea of the adverse conditions under which bearings and their lubricants must work. Take, for example, the main bearings of a jet engine.

These bearings operate in the vicinity of combustion chambers that reach temperatures of 4000°F. Rotating at 8000 rpm, they generate a quantity of heat internally as well—even though lubricating oil reduces friction. Insulated and shielded from the combustion burner's fierce heat, the bearings are additionally cooled to a more moderate 300° to 400° F.—as well as lubricated—by the flowing oil.

The oil's temperature is reduced in turn by outside air reaching the walls of an oil cooler. But at 2½ times the speed of sound, outside air hitting the walls generates a temperature of 500°F. on the cooling tank. Thus you see that the temperature of the main bearings, though cooled by the oil, will be much higher than the oil.

A fast-moving plane also has on board one other heat sink, or heat-dissipating source—the fuel. On its way to the combustion chambers—or even while still in its tank—the fuel absorbs many Btu's of heat. Already many calls are made on this small resource, however. Electronic equipment, for example, may be immersed right in the fuel to keep it cool. The human pilot, another item in the plane's control system, needs cooling too.

And so unquestionably, bearings and lubricants

are needed to function effectively at high temperatures.

Many groups throughout the country anticipated this problem in turbojets and other high-temperature engines. As a result, in recent years a number of advances were made in bearing science.

STATUS QUO

Initial steps beyond natural mineral oils have, in fact, already been taken. The result: synthetic oils. These have raised the limiting temperature of lubricating oils to around 500° F. In the latest jet engines for example, compounded synthetic oils remain stable to 400° F. or more. Additionally, their viscosity within the temperature range varies less than that of natural oils (Figure 1).

Today you can study a number of species of these new synthetics. Chemically speaking, they include polyesters, synthetic hydrocarbons, chlorinated hydrocarbons, polyethers, silicate esters—and most familiar to you, the silicones. All have disadvantages in some characteristics: large variations of viscosity with temperature; instability in the presence of heat, oxygen, or water; or inability to provide the boundary lubrication mentioned earlier. Still, one or more of these synthetics can probably be modified and adapted to carry conventional bearing systems to 600° or 700°F. if the lower temperature limits are relaxed.

Known fluids with a temperature range of −65° to +700°F. have been about exhausted as far as adapting them to conventional bearing systems. And so, bearing engineering of the future will heed the limits of fluid lubricants.

The advent of new bearing materials has matched the lubricant developments. Jet-engine bearings, more or less the conventional ball and roller types, are now being made of tool steels that maintain the necessary hardness and strength at high temperatures. Engineers have made other improvements, too, by choosing plating materials—silver, for example—that lubricate easily for use on ball and roller separators.

In applications other than flight-propulsion systems, such as nuclear-electric power stations, graphite bearings lubricated with water have been used successfully. True, water has an extremely low viscosity but becomes effective when pumped into a bearing under pressure. Further, it has the advantage of being an excellent coolant—often a secondary function of a lubricant.

What about the lightly loaded mechanisms as typified by clocks, instruments, baby buggies, thread guides, and so on? In these applications, plastic bearings are now used widely without any lubrication. Synthetic plastics like nylon are particularly useful in such applications because of their low coefficients of friction.

MODES OF TOMORROW

So much for the present. For the future this much

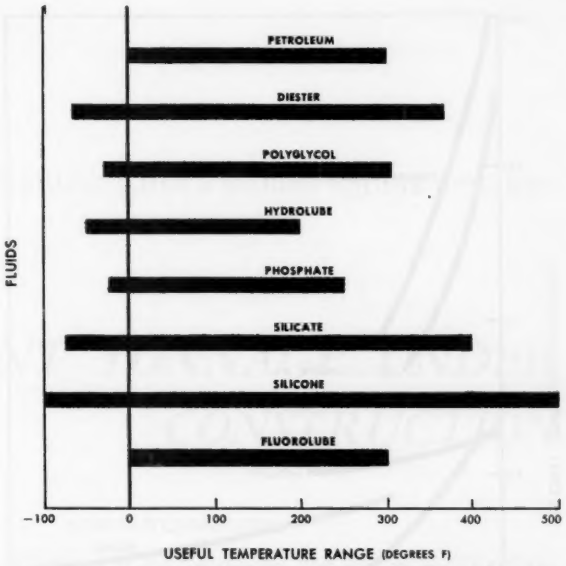

Figure 1. Operating Range of conventional bearings has been extended by recent developments of new organic fluids, silicones representing about the ultimate likely to be achieved.

is sure: You'll see the same basic types of bearings being used.

Design of bearing systems will become more flexible with the introduction of new materials and lubricants. Then too, design specifications will be modified. By eliminating the requirement that lubricants be fluid at −65° F. and by heating the oil where necessary, you'll be able to use lubricants more viscous at the highest temperatures. In other words, it's a matter of cutting off the low end of the temperature range and extending the high end.

These advances at the high end may be achieved by using molten, or chemically stable, materials that remain fluid over a wide temperature range. In either sleeve bearings or ball bearings, you may find metals like gallium and alloys of sodium and potassium as the fluid lubricants.

A few new organic materials also are stable at temperatures as high—and higher—than 1000°F. The oiliness of such fluids may have to be further developed. But their use appears feasible, once engineers stop insisting that lubricants be fluid at ordinary temperatures.

To utilize such fluids, ball bearings need more strength and fatigue resistance. The high pressure—and its cyclic application—that ball bearings are subjected to pose the real problem. Even the high-speed tool steels obtainable today lose strength rapidly at 1000°F. Perhaps acceptable substitutes may crop up among the sintered carbides (used for cutting tools), intermetallic compounds, newer alloys, or even ceramics.

Fatigue presents less of a problem in sleeve bearings. For these you may find that another type of lubricant will be adopted. Where a hydrodynamic

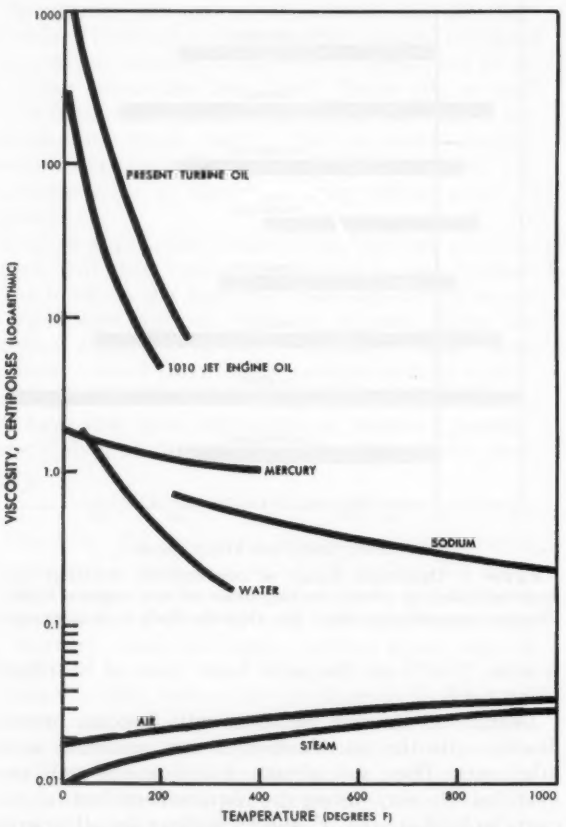

Figure 2. Viscosity of air and steam, unlike other lubricants, increases with temperature. Such gaseous lubricants may be feasible, but many problems remain to be solved.

barrier—or pressurized fluid film—is utilized, sleeve bearings require of their lubricants only viscosity. And the faster the shaft turns or the narrower the clearance between shaft and bearing, the less viscosity required.

Carried beyond ordinary extremes, you can interpret this to mean that gaseous lubricants are feasible. While air or steam as fluids may be low in viscosity, they have thermal and oxidation stability. Instead of decreasing with temperature, their viscosity improves (Figure 2).

Naturally, the use of steam as a lubricant is highly attractive to engineers designing steam turbines. A readily available product, it reduces fire hazards and problems of sealing. Perhaps one day you may even see an electric motor with its rotor turning and supported in air. The stator would be the only bearing. With heavy loads, the high pressure air from an auxiliary compressor could also be used to float the rotor on air.

These are fanciful schemes. Whether they will prove practicable depends on the magnitude of the technological problems they impose. For example, you can't overlook the possibility that at temperatures of 1000° or 2000° F., air and steam may corrode bearing materials.

The close clearance would require fine alignment. And the failure of the air or steam supply would immediately result in dry welding of the bearing surfaces.

How will these difficulties be surmounted? Perhaps the answer lies in the development of more efficient dry lubricants. With these, in fact, you could well eliminate all your other lubricant problems, such as chemical stability and the changes that occur in viscosity.

Already, dry lubricants like graphite and molybdenum disulfide satisfy some slow-speed applications. However, they do not form self-renewing boundary layers the way fluids do—a principal disadvantage. Eventually this results in loss of lubrication on the worn areas and, inevitably, failure. Needed to offset this disadvantage is an extremely tenacious dry lubricant coating or, lacking that, a means of continually rebuilding the boundary layer.

The first steps toward such lubricants have already been taken. Powdered molybdenum sulfide and graphite dusts, fed into rotating ball bearings by air stream, have successfully lubricated the bearings at temperatures as high as 1000° F.

Other dry materials—one of these boron nitride—also exhibit lubricity, that is, form boundary layers. A dry lubricant even more effective than graphite will possibly be discovered in the future.

NO MAGNETIC BEARINGS

Perhaps the most radical suggestion you've heard for a bearing fluid is the flux of a magnetic field. Unfortunately such an idea seems the least practical now. This suggestion has one drawback: you would need extremely high magnetic strengths to carry heavy loads. Coupled to this stands the discouraging fact that magnetic materials lose their magnetism as temperature increases. The magnetic suspension for watthour meters where loads and speeds are negligible has, however, achieved outstanding success.

NO RADICAL CHANGES

And so, finally, you have to conclude that bearings of the future won't be radically different from today's. Innovations will be generally a switch to new high-temperature bearing materials—perhaps a shift to either gaseous or solid lubricants.

By and large, high-performance machinery of the future will have the same bearing design as the chariots of Casear's Rome.

THE MERCHANT TONNAGE UNDER CONSTRUCTION

ACKNOWLEDGEMENT

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THE STATISTICAL returns of Lloyd's Register of Shipping for the quarter ended 30th June, 1956, show that work in hand at British shipyards totalled 334 vessels, of 2,028,132 tons gross, a decrease of 232,817 tons as compared with the figures for the previous quarter. The tonnage completed during the quarter (as shown in Table I) was exceptional, the total of 82 vessels, of 516,763 tons, being the highest since 1921. That high figure was, of course, assisted by the delivery during the period, of a number of important passenger liners for British and overseas owners. The tonnage begun totalled 62 ships, of 277,108 tons, and launchings amounted to 76 ships, of 306,053 tons. Work in hand in the principal centers is detailed in Table II.

The total amount of tonnage being prepared at shipyards in Great Britain and Northern Ireland at the end of the quarter amounted to 275 vessels of 2,116,962 tons, which was an increase of 398,310 tons over the corresponding figure for March. The latest total has progressively increased during the past 12 months. At the end of June last year, the total was 219 ships, of 1,322,699 tons gross. The total tonnage being prepared and under construction has also progressively increased in the past year, and, at the end of June, amounted to 609 vessels of 4,145,094 tons.

Tonnage under construction for registration abroad, or for sale, at the end of June (shown in Table III) amounted to 74 ships of 464,905 tons, which was 263,636 tons less than at the end of March last and the lowest since September, 1946. The figure represented only 22.9 per cent of the total tonnage being built in this country, as compared with 40.4 per cent when the peak figure of 825,745 tons was recorded in September, 1950.

TABLE I—*Vessels Commenced, Launched and Completed in Great Britain and Northern Ireland during the Quarter ended June, 1956*

Class	Commenced		Launched		Completed	
	No.	Tons Gross	No.	Tons Gross	No.	Tons Gross
Steamships	11	121,210	18	136,773	21	284,156
Motorships	51	155,898	58	169,280	61	232,607
Totals	62	277,108	76	306,053	82	516,763

TABLE II—*Merchant Tonnage under Construction in the Principal Districts of Great Britain and Northern Ireland*

District	June, 1956		March, 1956		June, 1955	
	No.	Tons Gross	No.	Tons Gross	No.	Tons Gross
Aberdeen	19	21,204	19	21,755	22	24,567
Barrow	3	71,930	3	83,140	4	86,000
Belfast	19	206,170	22	261,731	18	223,690
Bristol	4	2,717	4	2,660	4	2,030
Clyde:—						
Glasgow	70	419,750	75	459,127	75	443,224
Greenock ...	28	187,745	31	218,553	32	216,732
Dundee	6	44,410	5	36,410	6	35,110
Hartlepool	7	47,350	7	47,488	7	42,894
Hull	38	21,092	37	21,001	33	18,214
Leith	13	57,916	15	56,640	16	57,990
Liverpool	21	162,168	23	196,070	19	153,462
Middlesbrough	15	198,400	13	194,600	12	168,523
Newcastle-on-Tyne	34	372,589	37	397,066	37	391,570
Southampton ..	3	646	5	1,648	3	1,734
Sunderland ...	28	202,806	32	249,143	28	202,760

TABLE III—*Merchant Ships Under Construction in Great Britain and Northern Ireland and Intended for Registration Abroad*

Destination	No.	Tons Gross
Australia	4	10,200
Canada	4	15,954
India	1	4,450
Other British Commonwealth Countries	8	15,332
Belgium	2	1,620
Brazil	1	1,160
Greece	7	59,100
Honduras	3	20,500
Irish Republic	7	48,020
Liberia	9	95,740
Norway	9	89,404
Panama	2	30,400
Russia (U.S.S.R.)	10	6,850
Venezuela	3	915
Country not stated	4	65,260
Totals	74	464,905

Of the total tonnage under construction in this country, 62 vessels, of 833,301 tons gross, were oil-tank ships—a decrease of 111,963 tons as compared with the figures for the quarter ended March last, and representing 41.1 per cent of the total under construction. The various types of ships are detailed in Table IV.

TABLE IV—*Types of Ships, Including Oil-Tank Vessels, under Construction and in Preparation in Great Britain and Northern Ireland*

Types of Ships	Under Construction		In Preparation	
	No.	Tons Gross	No.	Tons Gross
Passenger ships and passenger/cargo liners	20	187,919	5	26,930
Cargo liners	88	603,032	79	510,201
Cargo tramps	30	204,045	30	187,340
Oil-tank ships	62	833,301	79	1,212,670
Ore-carriers	11	114,560	14	139,060
Colliers	7	17,910	5	11,000
Coasting ships	21	19,523	7	7,360
Miscellaneous	95	47,842	56	22,401

Apart from such quarterly fluctuations, the overall position of the industry is satisfactory. The flow of new orders, including those placed by owners overseas, is gratifying and might have been even larger had suitable berths and delivery dates been available. Most of the larger yards have order books in hand sufficient to ensure sustained production until about 1960. Less is heard these days of the cost of new ships. It may be that those shipowners who were most critical of the cost of new tonnage feel that the strength of the freight market, and the effect which higher freight rates have had in adding to transport costs eventually to be absorbed in the cost of materials, including those required for shipbuilding, discount the impact of their argument. More popular themes today, for which there is no lack of inspiration, are taxation and the equally popular one of "flags of convenience."

But while the thrust and parry of utterance and criticism between such old and respected friends and colleagues as those of shipbuilding and shipping may change with the times, and though present figures give rise to justifiable satisfaction in relation to the broader, global front, it could be argued that they might well have been better.

For the fact remains that, while order books are healthy and the June quarter produced an excellent total of completions, the overall productivity of the British shipbuilding industry shows no notable expansion and continues to run at the rate of about 1,250,000 tons a year, as it has been doing for what could be said to be too long, relative to the vast amount of capital expended in modernization and expansion in the post-war years.

There are several important reasons why production has not progressed to a potential that might be put at around 1,750,000 tons a year. The period of modernization has been harassed by uncertainty of material supplies, of which quite the most formidable one has been the fluctuations and uncertainties in steel supplies and delivery dates.

That problem has been growing more difficult in recent months, and the prospect is that it may become even more so in the final months of the year. The dispute in the iron and steel industry has retarded production, and, even though the threatened strike was averted, the continuance of the ban on overtime by maintenance men (at the time of writing) has tended to have an accumulative effect. The overall position worsened as the result of the strike in the American steel industry, causing a keener shortage in European supplies generally and those elsewhere.

It is a matter for speculation as to how far production in British shipyards might have been increased had steel supplies been adequate and deliveries of requirements of plates, bars, angles, etc., had been according to shipbuilders' construction and planning schedules. There seems little doubt but that results generally would have been better than they have been. As it is, shipbuilders have done remarkably well to maintain launching and completion schedules as they have done in recent months, but it cannot be denied that the prospects of schedules being maintained in the next month or two are less rosy, to say the least. There must be a few yards which have not been confronted with frustrating delays because of the hold-up in the delivery of special requirements to complete a vessel for launching.

That is not to blame steelmakers for shortcomings which, in the circumstances confronting them, can scarcely be regarded as anything but inevitable. They, too, have very considerable order books, both in respect to home and inland trade. The credit squeeze may possibly be easing the demand from some directions, but the overall demand remains formidable and, on present outlook, promises to continue to be so for some considerable time.

Until the dispute, the iron and steel industry had responded to the challenge of demand, both from

home and abroad, with a virility and a vigor which produced output records as consistently broken by higher figures; and this despite the fact that the industry has been the object (or, might it be said, the victim?) of political aspirations.

Such aspects of production in shipbuilding and the iron and steel industry assume more practical significance when viewed in relation to the expansion in shipbuilding productivity abroad. At the end of June, the tonnage under construction abroad amounted to 1,200 ships of 5,194,872 tons gross, an increase of 446,642 tons as compared with the figures for the previous quarter. The figures, as usual, exclude those for Poland, Russia and China, which are not available.

Under construction in the world at the end of June were 1,534 vessels of 7,223,004 tons gross, of which 28.1 per cent was being built in Great Britain and Northern Ireland. Details are shown in Table V and oil-carrying ships are given in Table VI.

The post-war recovery in shipbuilding abroad is self-evident, but it is doubtful whether its progressive expansion in the past few years is as fully appreciated as it deserves to be. Reference to the statistical returns of Lloyd's Register of Shipping for December, 1950, for instance, indicates just how sustained that recovery and expansion have been. At that date, the work in hand at British shipyards totalled 2,044,688 tons, which compares with 2,028,132 tons at June, 1956.

The work in hand at shipyards abroad at the end of December, 1950, amounted to 2,774,065 tons. Between then and June last, that total had practically doubled to 5,194,872 tons. At December, 1950, there was under construction 4,818,753 tons gross of merchant shipping, of which 42.8 per cent was being built in Great Britain and Northern Ireland. At the end of June last, the comparative figures were 7,223,004 tons and 29.1 per cent. Of course, the fact that Britain, today, is building only 28.1 per cent of the world's merchant tonnage, as compared with 42.8 per cent at December, 1950, is not because Britain is building less, but because the rest of the world is building so much more. Britain's share has steadily diminished since 1950. By June, 1952, for instance, 5,614,183 tons was under construction in the world, of which Britain was building 37 per cent, while her own work in hand at that date was 2,076,241 tons or, roughly, 48,000 tons more than the latest figure.

Such comparisons might have little more than academic interest, but for the fact that world potential has not only increased at a remarkable rate, but, presumably, is here to stay. As the shipbuilding industry of the world stands today, that is of no imme-

TABLE V—*Merchant Ships under Construction in the World (Excluding Ships of Less than 100 Tons Gross)*

Country of Build	Total			Total for Previous Quarter	
	No.	Tons Gross	Per Cent of World Tonnage	No.	Tons Gross
Great Britain and Northern Ireland	334	2,028,132	28.08	355	2,260,949
Australia	12	64,092		12	57,242
Canada	19	18,806		20	19,744
India	14	28,087	1.78	15	28,817
Other British Commonwealth Countries	19	17,497		17	16,701
Belgium	32	171,546	2.38	29	145,828
Denmark	26	130,718	1.81	30	122,417
Finland	51	104,204	1.44	49	89,480
France	70	386,365	5.35	77	469,817
Germany	251	806,679	11.17	261	770,865
Hungary	2	800	0.01	2	800
Iceland	1	200	0.00	1	200
Indonesia	4	2,400	0.03	7	2,700
Irish Republic	1	2,000	0.03	1	2,000
Italy	105	651,889	9.03	107	505,559
Japan	129	1,116,490	15.46	109	1,001,709
Netherlands	179	583,560	8.08	162	477,258
Norway	78	253,799	3.51	74	251,143
Portugal	9	16,655	0.23	11	18,360
Spain	67	164,010	2.27	67	152,828
Sweden	69	369,199	5.11	70	366,630
Turkey	9	7,340	0.10	9	6,640
United States of America	31	197,269	2.73	23	142,425
Yugoslavia	22	101,267	1.40	22	99,067
World Totals	1,534	7,223,004	100.00	1,530	7,009,179

TABLE VI—*Oil-carrying Ships under Construction in the World*

Country of Build	Steamships		Motorships		Total	
	No.	Tons Gross	No.	Tons Gross	No.	Tons Gross
Great Britain and Northern Ireland	44	763,904	18	69,397	62	833,301
Other Commonwealth Countries	—	—	4	792	4	792
Belgium	4	56,700	1	15,000	5	71,700
Denmark	1	12,200	2	35,300	3	47,500
Finland	—	—	1	3,200	1	3,200
France	5	145,270	3	38,370	8	183,640
Germany	3	62,200	20	23,350	23	85,550
Italy	11	216,552	8	27,799	19	244,351
Japan	22	543,500	12	74,705	34	618,205
Netherlands	8	138,221	3	34,110	11	172,331
Norway	1	12,300	14	143,861	15	156,161
Portugal	—	—	2	12,050	2	12,050
Spain	—	—	7	57,643	7	57,643
Sweden	2	46,700	10	107,396	12	154,096
United States of America	9	182,100	1	1,100	10	183,200
Yugoslavia	—	—	1	300	1	300
Totals	110	2,179,647	107	644,373	217	2,824,020

diate hardship to Britain's shipbuilding industry, which is both active and flourishing; but only the optimistic could view the expansion in overseas productivity, compared with the too static figures of British shipbuilding's productivity, without pausing to consider the implications which could arise in the future.

With global industrial and productive expansion increasing as vigorously as it is today, the outlook for shipping and shipbuilding is heartening. The demand for oil and basic materials, and the healthy state of global trade as a whole, promises to be maintained and, indeed, increased in the next year or two, bringing a corresponding demand for modern, specialized and more efficient tonnage.

There is justification for the belief that global shipbuilding capacity will continue to be occupied over the next year or two, even though, at present at least, there seems little sign that Britain will regain a larger share of the building. But the more realistic cannot ignore the fact that, should global demand for tonnage decline, then Britain would be now faced with an immense shipbuilding potential abroad, some of it with modern facilities and equipment, and no doubt determined to win its full share of the orders going.

That is the sort of realism which either escapes some of the labor leadership in this country or which they choose to ignore. The fact that British shipbuilding productivity has shown so relatively little increase is scarcely reflective of the potential of which it might be capable, following the modernization and expansion of recent years.

That higher output has not been achieved is due not only to materials shortages, but to the fact that restrictive practices and disputes have retarded what is, today, a machine whose potential efficiency is equal, for the most part, to anything anywhere abroad. How can maximum output be reached when, much too often, the engine timing, as it were, is set at retard? As it was with that absurd dispute at Birkenhead, while rival factions argued as to who should bore the holes in the aluminum plate. As it has been in a number of disputes eslewhere, when new methods and new materials have raised archaic issues of which craft does what, and no one really knows the answer and each claimant indignantly protests his right.

The foreigner regarding such disputes may, indeed, be nonplussed that a British industry, which has spent, and is spending, millions in modernization of its plant and facilities, should find that the archaic must still be regarded as something akin to sacrosanct. It would be difficult for labor leadership to argue that it is regarded as anything else. What is happening abroad appears to be inconsequential alongside the insistence that the tenets of demarcation be observed and preserved. That production is retarded, deliveries delayed and new orders jeopardized are apparently of minor consideration compared to such tremendous issues as to who shall bore holes in aluminum sheets, or who will fix fittings once made of wood and now made of metal.

The absurdity of it all reaches its pathetic climax with the retort that the only way to make the future of the shipbuilding industry secure is to nationalize it. Presumably, once nationalized, the industry would have found the solution of dealing with the competition which the rest of the world could exert, should circumstances demand. If there is one glaring weakness in labor leadership today, it is its apparent reluctance to stop looking over its shoulder at its customs and usages and its seeming inability to look no further forward than today. Maybe there is that altruistic view which takes heart in the hope that if, or when, global competition should arise, the workers of the world will by then be united in a common cause which guarantees hours, pay and conditions, with no man getting more or doing better than the next.

Pending the arrival of such a congenial state of affairs, workers and management in Japan and Germany are "going to it" in no uncertain manner and with apparently but slight consideration for any global shares-for-all. If the British worker is content with his share and contribution to global shipbuilding productivity, it would seem that the Japanese and the German workers have greater ambitions. In December, 1950, the Japanese shipbuilding industry was scarcely getting into its post-war stride. It was sixth in the list of leading countries abroad, with only 231,350 tons of merchant shipping under construction. Germany was seventh, with 197,510 tons. By June, 1952, Japan had come up to second place with 456,633 tons, while Germany was third, with 405,806 tons. By June last, Japan was stoutly entrenched in first place, which it had already won, and had under construction 1,116,490 tons—an increase of 114,781 tons on the March quarter.

Except in the completion of tonnage, the Japanese shipbuilding industry was busier, for the quarter ended June last, than Britain. The tonnage commenced totalled 90 ships, of 447,292 tons, as compared with Britain's 62 ships of 277,108 tons. The launchings for the quarter, from Japanese yards, totalled 71 ships of 322,704 tons, as compared with Britain's 76 ships of 306,053 tons. The completions totalled 70 ships of 355,520 tons, against Britain's 82 ships of 516,763 tons. There seems to be little doubt but that the Japanese shipyard worker had an active quarter, and the fact that he helped to commence, launch and complete so much tonnage was primarily, of course, due to the fact that a considerable number of overseas owners had placed orders with his industry. At the end of June, his industry had under construction 129 ships of 1,116,490 tons, of which 68 ships of 264,782 tons were for registration in Japan, and 61 ships of 851,708 tons for elsewhere.

On the other hand, the British shipyard worker's industry was building 260 ships, of 1,563,227 tons, for the British mercantile marine, and 74 ships, of 464,905 tons, for other flags. A glance at the respective figures shows that the British worker has the British shipping industry to thank for a good deal of his sustained employment, while the Japanese worker must be obliged to the world at large for the greater part of his. It is a reasonable question to ask whether the Japanese worker would complacently allow his share of global orders to slip from him, should circumstances arise in which the British worker required a bigger slice of those orders to keep him busy. It is, indeed, a question which might aptly be added to any agenda devoted to such problems of work allocation which arise with demarcation. It might prompt an interesting discussion on the wider prospects of not so much as to who bores the holes in aluminum sheets, but whether the holes will be bored in this country or in Japan.

The question might well include Germany, because the comparative figures merit it. During the quarter ended June last, Germany commenced 100 ships of 328,787 tons gross, as compared with Britain's 62 vessels of 277,108 tons. She launched 111 ships of 289,207 tons (76 ships of 306,053 tons) and completed 110 vessels of 278,586 tons (82 ships of 516,763 tons). Germany thus commenced more tonnage than Britain during the quarter, though launchings and completions were fewer. The German worker, like the Japanese, has reason to be thankful for the patronage of overseas shipowners. Of the 251 ships of 806,679 tons under construction, 118 vessels of 259,513 tons were for registration in Western Germany, and 133 ships of 547,166 tons were for registration elsewhere. Thus, for every ton under construction for registration at home, the Japanese worker was building more than 3 tons for export, the German worker more than 2 tons, and the British worker less than one-third ton.

Admittedly, these are quarterly figures, and thus tend to fluctuate over so short a comparative period, but the general trend and its inference are surely undeniable.

That the Japanese and German worker to mention the biggest contributors in the export field, should be building, respectively, more each than the British worker for overseas shipowners is not, of course, a reflection of competitive capacity so much as of the needs and circumstances of the respective national shipping industries. No doubt British yards would have been more active in building for export if berths had not been already so extensively occupied in building for British owners. The point is that the Japanese and German shipbuilding industries, in particular, have been able to re-equip themselves speedily enough, and to find the man-power, to meet global demand for tonnage on a large scale, and to prove that they can build tonnage to satisfy the shipowners of the world in general.

That is not to lose sight of the fact that Britain still leads the shipbuilding countries of the world, and there is no reason to suspect that she will lose her proud position. At the end of June last, she had under construction nearly twice as much tonnage as Japan, and more than twice that of Germany. But that leadership would surely be all the more secure were productivity in British yards given the impetus modernization deserves, by a far more realistic and practical co-operation and understanding on the part of labor and its leadership than have been apparent during the period when production and potential competition abroad have so manifestly strengthened.

The leading countries abroad (showing also tonnage fluctuations as compared with the figures for the previous quarter) were Japan, 1,116,490 tons (+114,781 tons); Germany, 806,679 tons (+35,814 tons); Italy, 651,889 tons (+146,330 tons); Netherlands, 583,560 tons (+106,302 tons); France, 386,365 tons (−83,452 tons); Sweden, 369,199 tons (+2,569 tons); Norway, 253,799 tons (+2,656 tons); United States of America, 197,269 tons (+54,844 tons); Belgium, 171,546 tons (+25,718 tons); Spain, 164,100 tons (+11,182 tons); Denmark, 130,718 tons (+8,301

tons); Finland, 194,204 tons (+14,724 tons); and Yugoslavia, 101,267 tons (+2,200 tons).

Progress abroad during the quarter was as follows:—Commenced, 379 ships of 1,608,934 tons; launched, 389 ships of 1,281,649 tons; and completed, 345 ships of 1,184,364 tons. Work was suspended on 15 ships of 5,190 tons.

The tonnage intended for registration elsewhere than in the country of build showed an increase of 322,464 tons to 2,473,813 tons (47.6 per cent of the total under construction abroad), including 598,084 tons for Liberia, 478,210 tons for Panama, 425,882 tons for Norway, 160,488 tons for Russia and 162,060 tons for the United States of America.

The countries abroad in which the largest amounts of such tonnage were being built were Japan (851,708 tons), Germany (547,166 tons), Sweden (272,252 tons) and France (214,376 tons), representing 76.3, 67.8, 73.7 and 55.5 per cent, respectively, of the tonnage under construction in those countries.

The oil-tank vessels under construction totalled 155 ships of 1,990,719 tons gross, which was 267,239 tons more than in March last, and represented 38.3 per cent of the total tonnage being built abroad.

They included 34 ships of 618,205 tons under construction in Japan; 19 ships of 244,352 tons in Italy; eight ships of 183,640 tons in France; 10 ships of 183,200 tons in the United States of America; 11 ships of 172,331 tons in the Netherlands; 15 ships of 156,161 tons in Norway; and 12 ships of 154,096 tons in Sweden.

Apart from those countries excluded, there were under construction in the world 1,534 steamships and motorships, of 7,223,004 tons gross, of which 28.1 per cent was being built in Great Britain and Northern Ireland. The total showed an increase of 213,825 tons as compared with that for the previous quarter.

The ships being built in the world at the end of June included 26 steamships and 135 motorships of between 6,000 and 8,000 tons each; 25 steamships and 108 motorships of between 8,000 and 10,000 tons; 49 steamships and 64 motorships of between 10,000 and 15,000 tons; 18 steamships and eight motorships of between 15,000 and 20,000 tons; 55 steamships and six motorships of between 20,000 and 25,000 tons; 14 steamships between 25,000 and 30,000 tons each; five steamships estimated at between 30,000 and 35,000 tons; and a steam-turbine oil-tank ship of approximately 50,000 tons gross in Japan, for Liberia.

Of the total under construction in Great Britain and Northern Ireland at the end of June, 1,150,852 tons consisted of steamships and 877,280 tons of motorships; while, at the same date, the tonnage being constructed abroad comprised 2,061,640 tons of steamships and 3,133,232 tons of motorships.

The total tonnage under construction in the world for countries other than the country of build amounted to 2,938,718 tons, of which 15.8 per cent was being built in Great Britain and Northern Ireland.

Countries importing the largest amounts of new tonnage were Liberia (693,824 tons), Norway (515,286 tons) and Panama (508,610 tons); while the countries making the largest additions to their existing fleets were Great Britain and Northern Ireland (1,700,956 tons); Norway (764,540 tons), Liberia (693,824 tons), Italy (519,022 tons), the Netherlands (510,870 tons), Panama (508,610 tons), the United States of America (353,719 tons), Japan (264,782 tons), Germany (259,513 tons) and Sweden (203,347 tons).

Oil-tank vessels under construction in the world amounted to 217 ships of 2,824,020 tons gross (110 steamships of 2,179,647 tons and 107 motorships of 644,373 tons), which was 155,276 tons more than for the previous quarter. Although the oil-tanker percentage of the total tonnage under construction in the world had thus risen from 38.1 to 39.1, it was still the lowest percentage since June, 1951. The peak figure was 58.5 per cent, in September, 1954.

Of this oil-tanker tonnage, 54 ships of 705,231 tons were for registration in Great Britain and Northern Ireland; 16 ships of 397,621 tons for Liberia; 17 ships of 377,170 tons for Panama; 27 ships of 340,161 tons for Norway; 14 ships of 239,860 tons for the United States of America; 15 ships of 171,751 tons for Italy; and 14 ships of 127,850 tons for the Netherlands.

Of the steam and motor merchant ships under construction throughout the world at the end of June, 4,448,648 tons (61.6 per cent) was under the inspection of officers of Lloyd's Register of Shipping. Of this total, 1,941,144 tons, representing 95.7 per cent of the tonnage being built there, was under construction in Great Britain and Northern Ireland; while of the tonnage being built abroad, 2,507,504 tons (48.3 per cent) was to be classed with Lloyd's Register of Shipping.

JOHN W. SAWYER

ENGINEERING ABSTRACTS

Number	*Abstract Title*
1–57	Corrosion
2–57	Vacuum Treating Nonferrous Metals at the U. S. Naval Gun Factory
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7–57	Bearings for Marine Geared Turbines
8–57	Cemented Oxides or Carbides?
9–57	What Causes Grinding Stresses
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11–57	First Closed Cycle Coal Burner
12–57	Motion Picture of Metal Fatigue
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14–57	Encyclopedia of Electrical Insulation
15–57	Problems Associated With the Productions and Use of Wrought Aluminum Alloys
16–57	Rational Design of Stayed Tube-Plates
17–57	The Seizing of Cylinder Joint Bolts
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21–57	Static Electrical Controls
22–57	Soldering "Unsolderable" Materials
23–57	Analysis of the Temperature Field in a Gas Turbine Rotor, Using a Hydraulic Integrator
24–57	A Preliminary Study of the Fatigue of Metals in Liquid Metal Environments
25–57	Protecting Molybdenum at High Temperatures

Number	*Abstract*
1–57	"Corrosion"—H. P. Kallen; Power, V. 100, n. 12, Dec. 1956, pp. 74–108. This report on corrosion includes the following: electrochemical theory of corrosion, how to recognize different types of corrosion, anti-corrosion weapons, combating plant corrosion, information from corrosion tests, establishing a corrosion control program. Corrosion causes, detection and methods of prevention are discussed for many components of prime movers, including: boiler tubes, boiler drum, feed heater regulator, piping, steam turbine blading, condenser tube sheet, diesel cylinder liner, condenser tube, diesel piston, economizer tubes, stud bolts, valves and reduction gears.
2–57	"Vacuum Treating Nonferrous Metals at the U. S. Naval Gun Factory"—V. De Pierre and S. Inouye; Foundary, V. 84, n. 12, Dec. 1956, pp. 108–114. The vacuum treating process for nonferrous metals, developed by the Naval Research Laboratory is being used at the U. S. Naval Gun Factory. Two production units are now in operation. These units have capacities for 200 and 600 pounds of aluminum and 600 and 1800 pounds of bronze. Test procedures and results are presented on aluminum alloys, copper and bronzes. This vacuum treating procedure for removing dissolved gases produced sounder castings and ingots. Future specifications for ingots, metals and master alloys may have maximum requirements for gas content.
3–57	"Lubrication in Presence of Nuclear Radiation"—J. G. Carroll and R. O. Bolt; Lubrication Engineering, V. 12, n. 5, Sept.-Oct. 1956, pp. 305–309. An investigation of the effects of pile radiation on lubrication of bearings and gears has been conducted. Work consisted of three parts: static irradiation, oxidation tests and lubrication tests.

ENGINEERING ABSTRACTS

Number *Abstract*

The lubrication tests are presented. This is the first unclassified description of the work. Tests, description of apparatus, torque data, wear data, falex test results, lubrication deterioration are presented. Tests indicate: overall lubrication process does not show change with quick decrease of neutron flux; life of lubricant is noticeably shortened by pile radiation; in presence of pile radiation the compounded sebacate fluid is better lubricant than the octadecylbenzene.

4–57 "The Use of Lignum Vitae as a Bearing Material"—W. T. Hide; The Shipbuilder and Marine Engine-Builder, V. 63, n. 583, Nov. 1956, pp. 644–646. Wearing properties of end grain and long grain of lignum vitae, when used as a lining for stern-tube bearings, has been investigated. Tests were conducted in two model stern-tube bushes. Shafting was rotated so as to give a rubbing speed of 8 ft. per sec. A series of tests was run, 1000 hours each, in 10 steps of about 100 hours continuous running. Wear in the bearing strips was measured after each 1000 hours operation. Test data show that in the most heavily loaded bearing wear on the long grain wood is two to three times that on the end grain.

5–57 "Metal Whiskers"—G. W. Sears and S. S. Brenner; Metal Progress, V. 70, n. 5, Nov. 1956, pp. 85–89. The tensile strength of iron whiskers has been measured as 1,900,000 psi. This test was made on an iron whisker 0.000,000,004 sq. in. in cross section. The test shows the elastic strengths for perfect crystals can be reached for actual crystals. Four methods of whisker growth are described. Whiskers offer several uses in research such as: experiments that require pure single crystals of known orientation, field of magnetism, studies involving precipitation and diffusion.

6–57 "Chromizing for Resistance to Corrosion and Wear"—D. E. Lehane and R. L. Wachtell; Product Engineering, V. 27, n. 12, Nov. 1956, pp. 180–183. Critical materials can be saved in many applications by chromizing. Gaseous diffusion of chromium on some non-ferrous and ferrous metals increases their resistance to oxidation, corrosion and wear. Ductile cases can be formed on low carbon steels by this process. The properties of the steel remain unchanged generally. Hard cases can also be formed and are used where abrasion is a problem. Applications of both ductile and hard cases are shown with material used and material which is replaced.

7–57 "Bearings for Marine Geared Turbines"—A. D. Newman; International Shipbuilding Progress, V. 3, n. 26, Oct. 1956, pp. 528–539. Reliability and efficiency are the two major requirements of geared turbines in marine service. Material presented includes: general requirements, various types of bearings, design parameters, length-diameter relationship, clearances necessary, grooves, inlets,

Number *Abstract*

materials, temperature measurement. Photographs, curves, tabulated data and references are included. The conclusions show: length/diameter ratio is in the range ⅓ to ½; thin shell bearings offer advantages.

8–57 "Cemented Oxides or Carbides?"—H. J. Siekmann; Machinery, V. 63, n. 2, Oct. 1956, pp. 204–209. Due to development of improved grades of carbides and cemented oxides, combined with proper tool design, machine cutting speeds have been extended in two directions, from the 100–1000 fpm, down to 0 and up to 3000 fpm. Carbide throw-away tips held in a mechanical holder combined with a cemented oxide tool reduced a particular cut time from more than 33 minutes to less than 1 minute. An AISI 6145 steel blank, 12 in. in diameter, was machined as follows: first, a carbide throw-away tip in a mechanical holder was used from the center outward until a speed of 600 fpm was reached; then a cemented oxide tool was brought into use until a speed of 2600 fpm was attained at the outer diameter.

9–57 "What Causes Grinding Stresses"—J. Harrington; American Machinist, V. 100, n. 22, Oct. 22, 1956, pp. 124–126. Research indicates that in grinding operations temperatures on metal surfaces approach 3000° F. At depths of 0.005 in. temperatures of 600° F. are approached. Surface stresses in the order of 270,000 psi have been generated in metal during grinding. Improper grinding can result in high residual stresses that can cause failure in service. Investigation of a shaft failure in a jet engine, which was stressed at peak load to 70,000 psi, showed that initial stress set up by grinding was about 69,000 psi. By improved grinding methods this stress was lowered to less than 700 psi.

10–57 "Low Pressure Performance of Cylindrical Can Type Burners"—M. A. Weiss and J. P. Longwell; Jet Propulsion, V. 26, n. 9, Sept. 1956, pp. 749–756. Can type burners were studied and tests conducted to investigate: combustion stability and efficiency of cylindrical cans at low atmospheres; effects of varying number and size of first stage inlet openings; diameter and length of recirculation zone; effects of changing pressure, mass flow, recirculation zone wall temperature and tailpipe length. Combustion stability and combustion efficiency are used to measure performance. Test equipment description, curves, tabulated data, and references presented.

11–57 "First Closed Cycle Coal Burner"—The Oil Engine and Gas Turbine; V. XXIV, n. 279, Mid-Nov. 1956, pp. 275–278. The first industrial closed cycle gas turbine plant burning pulverized coal was recently placed in operation in Ravensburg, Germany. The plant supplies up to 2,000 kw and all space heating for offices and shops. The closed cycle was selected in preference to a steam plant.

Number *Abstract*

Calculated efficiencies were 22% in summer and 19% in winter for the steam installation and 26% for the gas turbine plant. Power load fluctuations between 300 kw and 1800 kw made good part load efficiency necessary. Constant efficiency can be maintained from full down to about 40% load by changing cycle pressure and keeping maximum temperature constant. By use of inter-cooler and pre-cooler to supply space heating hot water an overall thermal efficiency of 56% is reached. The compressor, a three stage centrifugal, and an axial flow turbine are arranged in a single casing, requiring only two bearings. The rotor speed is 12,750 rpm. Maximum cycle pressure is 425 psi.

12–57 "Motion Picture of Metal Fatigue"—National Bureau of Standards Technical News Bulletin; V. 40, n. 11, Nov. 1956, pp. 153–154. Microscopic features of a metal surface during fatigue fracture can now be recorded on motion picture film. National Bureau of Standards has built a fatigue testing machine equipped with a motion picture camera. A clock controlled, 16-mm camera records time-lapse motion pictures of specimens under torsional stress. In testing aluminum under torsional stress slip bands appeared, then developed into cracks and a material of unknown composition was extruded from the cracks. This work is part of an investigation sponsored by the National Advisory Committee for Aeronautics to study basic factors influencing fatigue crack initiation.

13–57 "Some Theoretical and Practical Considerations of the Johnsen-Rahbek Effect"—A. D. Stukes; The Metropolitan Vickers Gazette, V. XXVII, n. 448, Nov. 1956, pp. 350–357. If two flat and polished plates, one a high resistance semi-conductor and the other metal, are placed in contact and a voltage is applied across them a force is developed that holds the plates together. This is known as the Johnsen-Rahbek effect. This force is proportional to the square of the applied voltage up to a certain point. Investigations have been conducted to apply this effect to electrostatic clutches, relays and valves to control gas flow rates. Clutches have operated 100,000 cycles in some cases and only a few hundred in others. Wear is critical in clutches and these units are not reliable. Future applications may be found in relays and valves where dry conditions are found.

14–57 "Encyclopedia of Electrical Insulation"—G. De Senarclens; Electrical Manufacturing, V. 58, n. 6, Dec. 1956, pp. 92–99. The International Electrotechnical Commission is sponsoring work to formulate design engineering data that can be used in the selection of optimum insulating materials. This is a progress report. Charts are presented on property characteristics and comparative factors. The comparative tables include: Group 34/36 Solvents, Hardenable Castings and Impregnating Resins; Group 13 Solid Three Dimensional Thermosetting Insulating Material; Group 31 Insulating Varnishes containing a Solvent Drying by Chemical and Physical Processes; Group 16 Solid "Spaciform" Laminated Insulating Materials; Group 8 Films and Sheets; Group 22 Hot-Bonding Laminated Materials for Winding or Flat Application; Group 14 Solid "Spaciform" Thermoplastic Nonlaminated Insulating Materials.

15–15 "Problems Associated with the Production and Use of Wrought Aluminum Alloys"—G. Forrest and K. Gunn; The Journal of the Royal Aeronautical Society, V. 60, n. 550, Oct. 1956, pp 635-658. Problems of production and use of heat-treated alloys are presented in detail. Material includes: remelting, alloying, casting, mechanical working, heat treatment, inspection, tensile properties, fatigue properties, stress corrosion, bending and forming. Photographs show metal flow in billets during extrusion operations. Tabulated data, curves, references and comments form a part of the paper.

16–57 "Rational Design of Stayed Tube-Plates"—J. P. Duncan; Engineering, Part I, V. 182, n. 4727, Oct. 12, 1956, pp. 459–463, Part II, V. 182, n. 479, Oct. 26, 1956, pp. 525–528. A method of designing stayed tube-plates is presented. Material includes: Theoretical argument, design data charts, eccentric loading test, eccentric loading of circular plates with encastré edges, evaluation of stay patterns, experimental confirmation and conclusions. This theoretical method permits calculation of loads in individual stays of symmetrically stayed tube-plates.

17–57 "The Seizing of Cylinder Joint Bolts" — S. H. Frederick; Pametrada Newsletter, n. 7, July 1956, p 1. Methods of preventing seizure and possible destruction of cylinder joint bolts on steam turbines are discussed. Seizures were not high when maximum steam temperature was about 750° F, when threads were coated with oil, graphite grease, mercuric paste, and when copper plated nuts were used. Higher steam temperatures resulted in a great increase in seizures. A series of tests was conducted at Pametrada to determine efficiency of various thread treatments. Tests included three high temperature bolt steels of the 1%Cr-Mo and 1% Cr-Mo-V types suitable for 900°F, 950°F and 1050°F. Most successful treatments were found with sulphided nuts and molybdenum disulphide grease.

18–57 "Recent Developments in Marine Diesels"—The Institute of Marine Engineers Transactions; V. LXVIII, n. 10, Oct. 1956, pp 365-426. A symposium of four papers including the following:

1. "Turbocharging of Burmeister and Wain Opposed Piston and Poppet Valve Engines—H. Carstennen. Turbocharging of opposed piston

Number *Abstract*

and poppet valve engines, design features and operating experience.

2. "Recent Developments in Marine Diesels (The Doxford Engine)"—P. Jackson. Developments relating to supercharging, sea experience, use of boiler fuel, improving efficiency and possible future developments are discussed.

3. "Some Aspects Concerning the Supercharging of Existing Two-Stroke Marine Diesel Engines"—W. Kilchenmann. Principal methods of supercharging and their merits are presented. Results presented on a number of supercharged two-stroke engines.

4. "Two-Stroke Marine Diesel Engines With Uniflow Scavenging and Constant Gas Pressure Turbocharging"—F. G. Van Asperen, H. Schultheiss. Modern pressure charging systems, description of uniflow scavenged turbocharged engine, experience with high viscosity fuels and future trends discussed.

19-57 "Motive Power on Sea and Land"—T. A. Crowe; The Engineer, No. I, V. 202, n. 5257, Oct. 26, 1956, pp 580-581, No. II, V. 202, n. 5258, Nov. 2, 1956, pp 614–616. The author discusses experiences relating to various modes of marine and railway power. Marine material relating to the Royal Navy includes: boilers and turbines and their development and application in vessels including cruisers and destroyers; cruising turbine clutches; gland evacuation systems and flexible shaft bulkhead seals. Diesel plants for locomotives with hydraulic couplings and torque converters are discussed.

20-57 "The Navy Patent Organization"—G. N. Robillard; Office of Naval Research Reviews, Oct. 1956, pp 1-5. This organization consists of Assistant Chief of Naval Research for Patents and Patent Counsel for the Navy, Civilian Patent Counsel, Patent Administrator and a Patents Legal Division. Four patents divisions provide service for ONR, Bureau of Aeronautics, Bureau of Ordnance, and Bureau of Ships. The Navy Patent Organization has to date received more than 16,000 invention disclosures, conducted some 9,000 patentability searches and obtained issuance of about 4,500 patents. Known dollar savings per year average about $3,000,000 while the annual budget for the Patent Organization is about $1,000,000. Annual invention disclosures, averaged over three fiscal years, 1954-1956, numbered 2,042. Annual issuance during the same period averaged 468.

21-57 "Static Electrical Controls"—John C. Ponstingl; Machine Design, V. 28, n. 24, Nov. 29, 1956, pp 89-104. Improved reliability and lower maintenance costs are now being built into electric controls by using static electrical components such as resistors, saturable reactors, dry type rectifiers, crystals and thermocouples. Lack of moving parts and filaments is an advantage of the static components. Applications include: temperature measurement and control, safety and warning circuits, temperature compensation, voltage sensing applications, voltage surge protectors, automatic voltage control, infrared lead-sulfide light-beam applications, isolation of circuits, harmonic generators, applying sound on film and infrared detection. Tables, diagrams and photographs included.

22-57 "Soldering 'Unsolderable' Materials"—Joseph C. McGuire; The Tool Engineer, V. XXXVII, n. 5, Nov. 1956, pp 103-105. A unique method for soldering many materials usually considered unsolderable has been developed by the Los Alamos Scientific Laboratory. This method is simple and requires a hand grinder with an abrasive wheel, a stick of low-melting alloy, and the usual soldering materials. The method is described in detail. Materials that can be soldered by this technique include Pyrex glass, titanium, molybdenum, aluminum, tantalum, stainless steel, tungsten, ceramic, cobalt. Additional development work is needed to perfect the technique. Future applications may be made in electronics, laboratory and aircraft.

23-57 "Analysis of the Temperature Field in a Gas Turbine Rotor, Using a Hydraulic Integrator"—E. I. Molchanov; The Engineers' Digest, V. XVII, n. 11, Nov. 1956, pp 469-471, 474. A hydraulic integrator has been developed to permit analysis of the temperature distribution in gas turbine rotors under operating conditions. The integrator consists of a network of vessels of varying capacity and pipes with adjustable resistance to hydraulic flow. Operating principle of the integrator is explained. Results of an analysis of a turbine rotor are shown for a given set of operating conditions.

24-57 "A Preliminary Study of the Fatigue of Metals in Liquid Metal Environments" — J. W. Martin and G. C. Smith; Metallurgia, V. 54, n. 325, Nov. 1956, pp 227-232, 238. Use of liquid metals as coolants in engines and in nuclear applications points to a need to investigate corrosion fatigue of solid metals when in contact with the liquid metals. Two types of fatigue tests have been conducted: rotating bendings which were concerned with change in fatigue properties of copper alloys coated with mercury; push-pull tests on mild steel and 18/8 stainless steel in contact with liquid tin and liquid sodium, respectively, at 300°C. When stress limits are maintained well below the normal fatigue, with usual safety factors, premature failure may not occur due to the liquid metal. Further investigations are necessary in this field. References, S-N curves, photographs and tables are presented.

Number *Abstract*

25-57 "Protecting Molybdenum at High Temperatures" —J. J. Harwood; Materials and Methods, V. 44, n. 6, Dec. 1956, pp 84-89. The exceptional strength, at high temperature, of molybdenum base alloys has resulted in their consideration for certain military applications. The use of these materials for gas turbine blades and guide vanes is being considered. The materials have not been utilized because of the poor oxidization resistance. Coatings have been developed that protect the molybdenum base alloys. Electro-deposited chromium and nickel layers offer oxidization protection up to 2000°F. Sprayed coatings may protect up to 2400°F with certain ceramic and molybdenum discilicide coatings protecting at greater ranges. Electro-deposited coatings, claddings, sprayed metal coatings, diffusion coatings, molybdenum discilicide, ceramic coatings and surface barrier layers are discussed. Curves, tables, photographs and references.

BOOK REVIEWS AND NOTICES

BOOK REVIEW

HANDBOOK OF CHEMISTRY, NINTH EDITION
By Norbert Adolph Lange
Published in 1956 by
Handbook Publishers, Inc., Sandusky, Ohio
xvi + 1969 pp. $8.50
Reviewed by
Assistant Professor John G. Zimmerman
Department of Electrical Engineering
United States Naval Academy

This is the standard work in its field and has in its new edition undergone some careful revision. As has been the custom with this handbook the changes are chiefly in the form of revisions to the tables of the previous edition rather than the addition of new material. Many numerical values have been revised in an effort to correct errors and to bring the data up to date.

The order of the subject matter is essentially the same as in the previous edition:

Life and Fire Hazards
Chemical and Physical Properties of Classified Substances
Elements
Minerals
Inorganic Compounds
Organic Compounds
Industrial Materials
Chemical Analysis
Miscellaneous Tables of Specific Properties
Conversion Factors and Numerical Tables

Although less than two per cent of the bulk of the handbook is devoted to completely new material, there are actually some twenty new tables. Among the more noteworthy of these may be mentioned the "Polarography" table, which lists the half-wave potentials of inorganic ions and of organic compounds at 25° C.; this table is in keeping with the trend toward greater emphasis on physical methods in the field of analytical chemistry. Of interest to engineers is a table of "Mechanical, Physical, and Electrical Properties of Various Plastics." For those interested in making exact calorimetric measurements, "Heat Capacity Standards" tabulates to five significant figures the heat capacity of water, mercury, and aluminum oxide, over a wide temperature range. Also new is a chart which enables the user to make a quick, approximate conversion from any one of eighteen different viscosity scales to any other. Other new features deserving of mention, and which should appeal to a variety of users, are a table of the physical properties of sodium-potassium alloys, a comparison of the relative efficiency of various drying agents, a concise list of the fundamental constants of physical chemistry, and a table giving the elementary composition of the human body.

In order to keep the size of the handbook within reasonable bounds, the inclusion of new tables necessitated the streamlining of some of the tables of the eighth edition. This has been accomplished in some instances by deletion of less important data or compounds, in others by replacing lengthy tables of specific properties by concise equations which can be used to provide the same information, although not quite so readily. Many pages were saved, for example, in the tables of specific gravities of aqueous solutions by dropping the listing of such secondary information as grams of solute per liter, degrees

Baumé, etc., for many of the compounds. The table of "Organic Reagents for Inorganic Analysis" has been considerably condensed by the inclusion of a single reagent for each inorganic ion, rather than several. As illustrative of the use of equations to substitute for lengthy tables of data, the revised tables of "Vapor Pressures of Various Substances" may be cited. Extension of the section of these tables which gives the values of the constants of two equations for the vapor pressure has permitted the deletion of 150 individual tables for vapor pressure versus temperature. By such means, applied with apparent restraint, the editor has prevented the number of pages in the book from getting out of hand (the present edition actually contains some thirty pages less than the previous), without any appreciable loss in utility.

It will be noted with pleasure by former users of this handbook that many of the tables which have been revised now include more data than before, and in some cases more precise data. The "Table of Nuclides" has been expanded by inclusion of many additional isotopes, and cross-section and disintegration energy columns have been added. The standard calibration tables for thermocouples now list values to three decimal places instead of two, and a new table for chromel-constantan couples has been included, though the data for this table are listed to two decimal places only. The table of the "Physical Constants of the Elements" has been extensively revised and values of the volume change on fusion have been added. More liquids have been included in the table of "Dielectric Constants," and in addition the constants of a temperature-correction equation have been included where available. Nearly twice as many salts are now included in the tabulation of "Solutions for Maintaining Constant Humidity," and "Probable Values of the Physical Constants" contains a much more elaborate treatment of sources and error. In revising these and other tables the editor has made use of recent publications of the National Bureau of Standards, the American Society for Testing Materials, and other sources.

Only two tables in the eighth edition have been omitted in the present edition and these are not going to be missed by too many users of the handbook. One of them, "Fluorescence and Phosphorescence," a table listing the exciting wave length and fluorescent color for each of numerous separate compounds, has been replaced by a shorter table of "Phosphors" which gives fairly complete data for the composition and properties of several types of phosphorescent mixtures.

The index is, as in previous editions, thorough and replete with cross-references. It is conceivable, in fact, that many of the entries could be removed without material harm to the usefulness of the index.

The book is durably bound with a flexible cover and should withstand the hard usage to which any reference work of similar scope will customarily be put.

Lange's handbook has a definite place on the reference shelf of every chemist, chemistry teacher, chemistry student, and metallurgist, and of any engineer who is at all concerned with the properties of materials. This edition of the handbook represents a careful, scholarly attempt to bring the material up to date by revising much of the numerical data of the previous edition, by reorganizing some of the tables so that the information they contain is more generally useful, and by adding new material of increasing interest to the chemical world.

BOOK NOTICES

FUNDAMENTALS OF CONSTRUCTION AND STABILITY OF NAVAL SHIPS

by
Thomas C. Gillmer

Published in 1956 by
The United States Naval Institute
Annapolis, Maryland
370 pages — Price $6.00

This book is primarily intended as a textbook for the use of midshipmen during their final year in the Department of Marine Engineering at the United States Naval Academy. It is the text for their course "Naval Construction and Ship Stability," which course is under the supervision of the author, Associate Professor Gillmer.

The book is designed to familiarize future shipboard officers with the behavior characteristics of ships, their construction, capabilities and limitations. The emphasis is toward the control of damaged stability and damaged structure of naval ships, including a background in buoyancy, stability, ship resistance and many other ship characteristics. In brief, it is pointed toward the understanding of ships as a physical science.

As a text this book replaces "Fundamentals of Naval Construction and Ship Stability." The latter formed the basis around which the current book was written, but the revision was so drastic that a new

title was appropriate, rather than a revised edition of the older book. Briefly the changes include (a) a rearrangement of the material to provide a more logical overall sequence, (b) strengthening of the subjects of wave-making resistance, submerged resistance, ship strength, ship motion among waves, and dynamic stability, (c) introduction of wave motion in water, ship stabilization, and dynamically supported devices such as hydrofoils and water-based aircraft (P6M type), and (d) a change in ship example from DD348 to DD692.

The following are the chapter headings:

I. Planning and Building the Ship
II. Definitions and Geometry of the Ship
III. The Ship's Structure
IV. The Strength of Ships and Their Structural Material
V. Resistance, Propulsion and Steering
VI. Buoyancy
VII. Equilibrium and Initial Stability
VIII. Overall Stability
IX. Weight Effects on Stability
X. Impaired Stability
XI. Control of Damage
XII. Wave Motion in Water
XIII. Ship Motion Among Waves
XIV. Dynamic Stability
XV. Dynamically Supported Craft
XVI. Submersible Craft—The Submarine

INTRODUCTION TO THE BASIC MECHANISMS

by
Roy E. Hampton

Published in 1956 by
The United States Naval Institute
Annapolis, Maryland
249 pages — Price $4.50

Professor Hampton has written this book in order to modernize the approach to the subject by increased emphasis on the fundamental physical and mathematical principles involved. The generality of application of these principles is also given increased emphasis. The book is written in a manner to encourage the student to think through the principles involved in the basic mechanisms, so that the formulae will be tools mastered by the student, not rules to be memorized.

More specifically, the book has three main objectives: (1) to show the student the importance of definitions and distinctions among terms; (2) to insure understanding of the various basic mechanisms and their variations, combinations, and interrelations; and (3) to show the relationship of this course to the total training of an engineer, who must perceive relationships; select, evaluate, and organize pertinent data; and anticipate problems and their solutions.

As a text at the Naval Academy, this book replaces "Principles of the Basic Mechanisms." The scope of the new book is approximately the same as that of the book it replaces. The changes in the approach to the subject are so broad that a new title was appropriate rather than a revised edition of the old book. Throughout the book, there is more emphasis on the solution of problems by analytical thought processes rather than by application of formulae by rote.

The following are the chapter headings:

I. Introduction: Basic Definitions
II. Vectors
III. Velocity and Acceleration Analyses of Plane Motion
IV. Linkages
V. Rolling Bodies
VI. Cams
VII. Gearing
VIII. Gear Trains
IX. Flexible Connectors
X. Miscellaneous Mechanisms

INDUCTION HEATING PRACTICE

by
D. Warburton-Brown

Published in 1956 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N.Y.
192 pages—Price $10.00

High-frequency induction heating has come into use industrially only in comparatively recent years, but it is now very widely adopted in engineering wherever controlled heat is required: in brazing, soldering, hardening, annealing, tempering and similar operations.

This book is a detailed and up-to-date study of the process by a leading British expert, and deals par-

ticularly with its practical application to industrial problems. It is intended for the production engineer or executive interested in the possibilities of installing or extending induction-heating equipment, for the foreman or operator with the day-to-day job of operating (and sometimes adapting) such equipment, and for all others concerned with heat treatment in engineering production.

Chapter headings are as follows:

1 Brief Survey of Practical Aspects
2 Work-Coils and Inductors
3 Soldering by Induction Methods
4 Induction Brazing
5 Hardening by Induction Methods
6 Gear Hardening
7 Miscellaneous Applications
8 Component Design for Induction Heating
9 Locating Jigs and Handling Fixtures

PHOTOCONDUCTIVITY CONFERENCE

Edited by

R. G. Breckenridge, B. R. Russell and E. E. Hahn

Published in 1956 by

John Wiley & Sons, Inc.

New York, N.Y.

653 pages—Price $13.50

This book is a compilation of 30 papers presented at the Photoconductivity Conference held at Atlantic City, November 4–6, 1954. The conference, sponsored jointly by the University of Pennsylvania, the Radio Corporation of America, and the Office of Naval Research, was brought about by the increasing technical importance of the subject and the lack of adequate literature.

Altogether the 30 papers cover the work of 45 authors, and represent a broad, modern survey of the field of photoconductivity. The subject matter is arranged under the following five major headings:

I Phenomenological Theory of Photoconductivity (2 papers)
II Photon Absorption Process (6 papers)
III Electron Processes (6 papers)
IV Photoconducting Materials (7 papers)
V Current Topics (9 papers)

ENGINEERING INSPECTION, MEASUREMENT AND TESTING

by

H. C. Town and R. Colebourne

Published in 1956 by

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

192 pages—Price $8.75

This volume, which is profusely illustrated with photographs and diagrams, first explains the function of the modern factory inspection department, and briefly traces the development, up to the present day, of recognized standards and methods of measurement. Later chapters deal with the principles and practice of precision measurement and with comparators and other measuring and inspection machines. Special attention is given to measurement during machining and automatic sizing operations, and to screw-thread measurement, while a final chapter is devoted to the measurement of surface finish.

CALCULUS REFRESHER FOR TECHNICAL MEN

By A. Albert Klaf
New edition published in 1956 by
Dover Publications, Inc.
920 Broadway, New York 10, N.Y.
Paper bound 431 pages $1.95

This new edition is an unabridged re-publication of the first edition originally published in 1944. Its purpose is to provide a refresher on the fundamental concepts, methods, and practical applications of simple calculus.

The book is divided into three sections. The first covers simple differential calculus, with constants, variables, functions, increments, derivatives, differentiation, logarithms, curvature of curves, and similar topics. The second section covers simple integral calculus, including integration, areas, volumes, mean value, successive and partial integration, double and triple integration. The third section illustrates the application of calculus to specific problems in civil engineering, navigation, projectile flight, electricity, etc.

The book is not in the form of an ordinary textbook. It approaches the subject by answering 756 questions most likely to occur to the technical reader. The author, who is Civil Engineer of the New York City Board of Water Supply, stresses practical, rather than theoretical, aspects. Included in an appendix are 36 pages of useful constants, formulas and tables for ready reference.

TRIGONOMETRY REFRESHER FOR TECHNICAL MEN

By A. Albert Klaf
New edition published in 1956 by
Dover Publications, Inc.
920 Broadway, New York 10, N.Y.
Paper bound 629 pages $1.95

Like "Calculus Refresher for Technical Men," this book is an unabridged re-publication of the first edition originally published in 1946. And like the book on calculus, the subject is presented in question-and-answer form, by means of 913 questions and answers.

The first section covers plane trigonometry, including angles, quadrants, trigonometric functions, graphical representation, logarithms, significant figures, the slide rule, and solution of triangles. The second section deals with applications of plane trigonometry to navigation, surveying, architecture, etc. The third section is devoted to spherical trigonometry and the solution of spherical triangles, with particular application to terrestrial and astronomical problems.

ELECTRONIC COMPUTERS—PRINCIPLES AND APPLICATIONS

Edited by T. E. Ivall
Published in 1956 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N. Y.
167 pages $10.00

This book is neither a textbook nor an advanced treatise on the subject of computers. Rather it is a non-mathematical introduction to the principles and applications of computers, written for those who are on the fringe of the subject and may be thinking of going rather deeply into it, as well as for those who are just interested and do not wish to get too deeply involved.

Both digital and analogue computers are covered, and comparisons are made between the two types. Their circuitry, construction and industrial and scientific applications are described.

AN ENCYCLOPEDIA OF THE IRON & STEEL INDUSTRY

By A. K. Osborne
Published in 1956 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N.Y.
558 pages $25.00

This book provides, in encyclopedia form, a concise description of the materials, plant, tools and processes used in the iron and steel industry, as well as those industries closely allied to it. It also defines the technical terms employed.

It is intended for a reference book, not a textbook.

The author is Technical Librarian and Information Officer of Brown-Firth Research Laboratories, Sheffield, England.

MARINE NEWS DIRECTORY

Thirty-second Annual Edition, 1956–1957
Published in 1956 by
The New York Marine News Co., Inc.
26 Water Street, New York 4, N.Y.
532 pages $25.00

This directory is divided into the following sections:

1. American and Canadian Shipbuilding and Repair Yards.
2. American and Canadian Steamship and Waterway Lines.
3. American and Foreign Tankship Owners and Operators.
4. American and Canadian Dredging Companies.
5. Naval Architects, Marine Engineers, Consulting Engineers, Surveyors and Chief Draftsmen.
6. Port Section.
7. American Maritime Associations.
8. Naval Supplement, listing key personnel in various United States Government agencies.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society is very much pleased to state that the following have become members since the publication of the November, 1956, JOURNAL.

NAVAL

Anderson, Lloyd Craig, Machinist, USN
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Fleet P.O., San Francisco, Calif.

Bowersox, Earl Charles, Jr., Lieutenant, USNR
USS *Fletcher* (DDE 445)
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407 Mills Bldg., Washington, D.C.

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Havermeyer, Henry C., Civil Member
Kampf, Henry, Associate Member
Plascjack, Anthony M., Naval Member

RESIGNED

Abbott, George L., Associate
Allen, Scott E., Civil
Ball, Warren Wilson, Lieut., USNR, Naval
Belby, Michael, Associate
Bennett, Joseph S., Civil
Bennett, Lee C., Civil
Brandt, Weldon Henry, Civil
Davison, Ralph, Comdr., USN, Naval
Dodge, Wendell Phillips, Civil
Dragstrem, Bon B., Lieut. Comdr., USNR, Naval
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Watson, John Garth, Capt., R.N., Associate

DROPPED FROM ROLLS

It is regretted very much that it was necessary, in accordance with our By-Laws, to drop 69 members from our rolls on December 31, 1956, because of arrearage of two years in dues.

It is again a sad duty to report the death of the following, of which notice was received since the publication of the November, 1956, Journal.

Blanchard, Clement W., Civil Member
Creasy, Donald C., Naval Member
Krips, James A. C., Civil Member
Schnebelen, Joseph J., Civil Member
Simonds, Frank C., Civil Member
Watson, H. L., Civil Member
Yager, Ray F., Naval Member

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5 Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 4, D.C.

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Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

We have a new supply of lapel buttons, in the form of the Society's official seal. These may be purchased by any member for fifty cents ($0.50) each.

By decision of the Council the official coloring of the Society seal is as it appears on the cover of this Journal. This is a reversal of the colors on the old lapel buttons. The size, one-half inch in diameter, remains the same.

Any member who wishes to exchange an old button for a new one may do so *free of charge*. Just send in the old button with your name and address.

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Commissioned and ex-commissioned officers of the regular Navy, Marine Corps and Coast Guard of the United States; warrant and ex-warrant officers of the regular Navy, Coast Guard and Marine Corps of the United States; reserve commissioned and warrant officers of the Navy, Coast Guard and Marine Corps of the United States shall be eligible as Naval Members. Persons eligible as naval members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as civil members. They shall have been in active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as civil members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as associate members. Commissioned officers of the United States Army and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application have the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army and of foreign naval and military services, the recommendation of a member will not be required.

Associate members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $7.50, payable on 1 January in advance, of which $6.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

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